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Definition of Technology Development Missions for Early Space Stations

-Large Space Structures-

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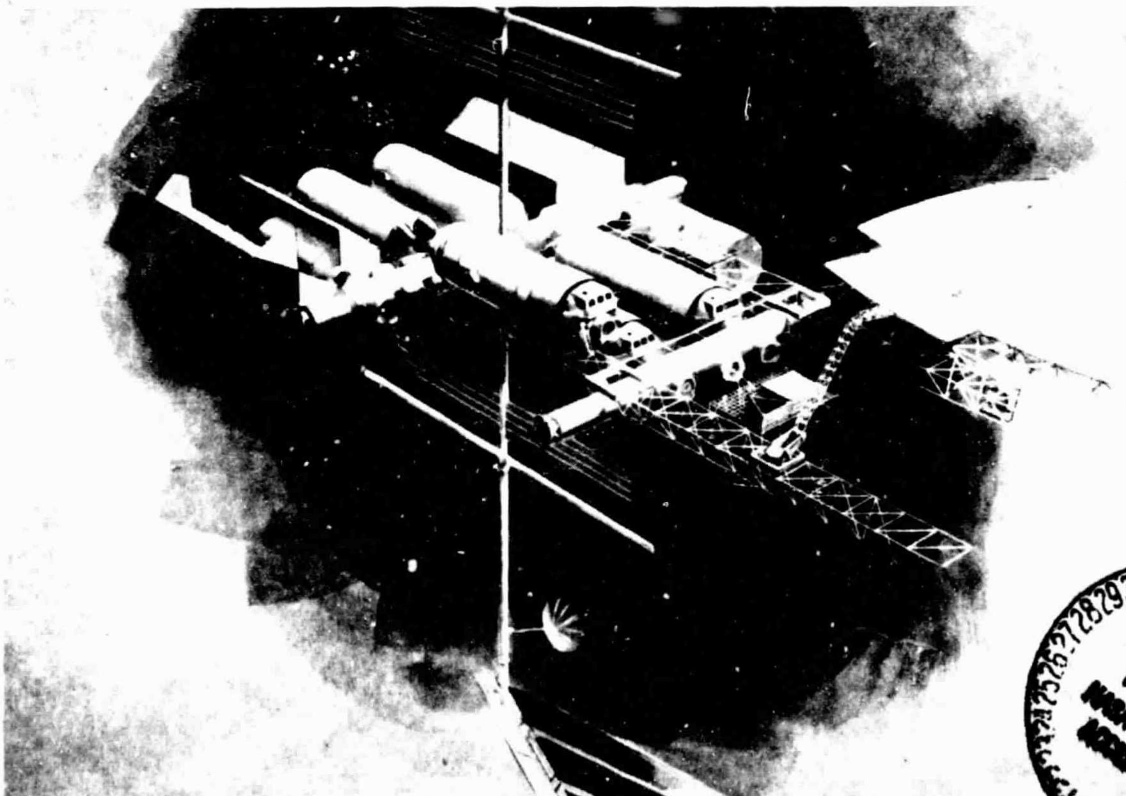

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DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATIONS

LARGE SPACE STRUCTURES

Contract NAS8-35043

D180-27677
Final Report

May 31, 1983

Prepared for the

National Aeronautics and Space Administration
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FOREWORD

This report presents the results of an eight-month study entitled, "Definition of Technology Development Missions for Early Space Stations—Large Space Structures". The study was conducted for the NASA-George C. Marshall Space Flight Center, Huntsville, Alabama by The Boeing Aerospace Company, Seattle, Washington. The work was performed under contract NAS8-35043 during the period 1 October 1982, through 31 May 1983, and was monitored by James K. Harrison of NASA. Mr. Richard M. Gates of Boeing was the Study Manager for the program. Structural designs of the technology development missions were accomplished by Mr. T. J. Vinopal and Mr. S. P. Robinson. Messrs K. H. Miller, G. Reid and A. G. Osgood performed the operational analysis and programmatics, and Mr. K. B. Vergowe performed the technology development mission hardware cost analysis.

The author wishes to express his thanks to the contributors mentioned above for their support to the program and to Mr. G. R. Woodcock for his guidance and technical contributions throughout the study.

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ACRONYMS

AIAA - American Institute of Aeronautics and Astronautics

C/O - Checkout

DAP - Digital Autopilot

EC/LS - Environmental Control/Life Support

EDP - Electronic Data Processing

EVA - Extravehicular Activity

FY - Fiscal Year

IOC - Initial Operational Capability

IVA - Intravehicular Activity

KW - Kilowatts

LMSC - Lockhead Missiles and Space Company

LRU - Line Replaceable Unit

LSS - Large Space Structure

LSST - Large Space Structures Technology

MCP - Mobile Cherrypicker

MOTV - Manned Orbital Transfer Vehicle

MRS - Microwave Radiometer System

MRWS - Manned Remote Workstation

NBS - Neutral Buoyancy Simulator

OTV - Orbital Transfer Vehicle

PCM - Parametric Cost Model

PRICE - Programmed Review of Information for Costing and Evaluation

RMS - Remote Manipulator System

SADE - Structural Assembly Demonstration Experiment

SAFE - Solar Array Flight Experiment

ACRONYMS (Continued)

SCE - Space Construction Experiment

S/C - Spacecraft

SE&I - System Engineering and Integration

SSTM - Space System Technology Model

STS - Space Transportation System

TBD - To Be Determined

T&CO - Test and Checkout

TDM - Technology Development Mission

TMS - Teleoperator Maneuvering System

VLBI - Very Long Baseline Interferometer

1.0 INTRODUCTION

With the advent of the space transportation system (STS) for delivery of spacecraft to low Earth orbit, the placing of large spacecraft systems in space will become more feasible. Advanced technology and more demanding mission goals will require the use of larger and larger spacecraft structures. To accomplish these missions it will be essential to use a Space Station for the demonstration of some large space structures (LSS) technologies that will require more time, support equipment and workspace than will be available with Shuttle sortie flight tests. Large space structures technology advancement is one of the keys for space platforms to become preeminent space systems of the future. The several ongoing Large Space Structures Technology (LSST) development programs throughout the aerospace industry will advance the technology through a series of ground tests and Shuttle flight tests. None of these planned LSST tests have taken into account the possible use of a Space Station.

The objectives of this study were to define the testbed role of an early (1990-95) manned Space Station in large space structures technology development and to conceptually design LSS technology development missions to be conducted at the Space Station. Emphasis was placed on defining requirements and benefits of development testing on a Space Station in concert with ground and Shuttle tests.

2.0 TECHNOLOGY DEVELOPMENT MISSION REQUIREMENTS

The first step in the design of large space structures (LSS) technology development missions is the determination of mission requirements. This was accomplished by identifying future missions which require large space structures, the timing of those missions and the objectives which must be demonstrated. LSS mission requirements were then determined for each of the identified objectives.

2.1 Evolutionary Technology Plan

To determine the specific requirements for LSS technology development missions (TDMs), the proposed uses of large space structures for future missions must be identified along with the timing of LSS needs. The associated ground tests and shuttle sortie flight tests must also be identified so that the TDMs result in a logical progression of LSS technology development.

With the STS as the orbital delivery system, space systems must be designed to utilize its capabilities while living within its physical and operational constraints. The features envisioned for an early space station must also be identified to make optimum use of its capabilities as a construction site for large space structures and to determine what additional features or equipment are required.

A discussion of each of these topics follows in the subsequent subsections leading into an integrated time-phased LSS mission scenario. These tasks led to an understanding of the current and future plans for space and the means available for demonstrating the technologies and techniques required for constructing LSSs in space.

2.1.1 Missions Requiring Large Space Structures

The definition of LSS technology develoment missions must be responsive to the needs of future space missions which require large space structures. Long range plans for space were assembled by reviewing published sources such as Large Space Systems Technology (LSST) program annual technical reviews [1-3], NASA Space Systems Technology Models (SSTM) [4, 5], military SSTM [6], past Space Station and space platform studies [7-10], American Institute of Aeronautics and Astronautics (AIAA) publications, technical symposium papers, and technical committee assessments [11-23], and other government sponsored contract reports [24-33].

This collection of future space missions and accompanying preliminary configurations were screened to identify those missions which would require large space structures. The definition of "large" used in this study is any spacecraft structure (exclusive of deployable appendages such as solar arrays, small antennas, scientific experiments, etc.) which is too large to be contained within the Orbiter payload bay envelope. The spacecraft eliminated from consideration are those which use current technology (i.e., conventional sized spacecraft), spacecraft with no identified mission, spacecraft whose mission appeared to carry low priority, and spacecraft whose missions were assessed to be too far in the future for current consideration.

Table 2.1.1-1 contains the list of LSS missions which passed this initial screening process. Along with each mission is the approximate launch date reported in the literature, a revised launch date based on our assessment of technology readiness and mission viability, and observations relative to the need and application of the various types of spacecraft and missions. The list is divided into the missions identified in the NASA SSTM, AIAA technical reviews and the military SSTM.

Table 2.1.1-1. Future LSS Missions

KEY	MISSION	SSTM DATE	REVISED DATE	REMARKS
NASA IDENTIFIED MISSIONS				
A-15	VERY LONG BASE-LINE RADIO INTERFEROMETER	<1995	<1995	DOESN'T REQUIRE NEW LSS TECHNOLOGY
A-16	ORBITING SUBMILLIMETER TELESCOPE	EARLY 1990's	EARLY 1990's	STRONG SCIENCE RATIONALE FOR THIS MISSION 30m DIA 0.1mm DEVIATION
A-17	LARGE AMBIENT DEPLOY-ABLE IR TELESC.	EARLY 1990's	EARLY 1990's	A-16 AND A-17 MAY BE THE SAME INSTRUMENT
A-18	INFRARED INTERFER-OMETER	>1995	>1995	STRONG CONTENDER FOR EXTRA-SOLAR PLANET DETECTION
A-19	GRAVITY WAVE INTER-FEROMETER	>1995		PROBABLY WON'T REQUIRE LSS
A-20	COHERENT OPTICAL SYST. OF MODULAR IMAGING COLLECTORS (COSMIC)	>1995		OVERLAPS OTHER MISSIONS (THINNED APERTURE TELESCOPE)
A-21	LARGE OPTICAL/UV TELESCOPE	>1995	>1995	A BIGGER SPACE TELESCOPE WILL BE NEEDED BY THEN
A-22	100 METER THINNED APERTURE TELESCOPE	>1995	>1995	ALTERNATIVE TO A-20 — BROADER APPLICATION
E-11	OCEAN RESEARCH (SAR)	1989	1995	SOME SORT OF SAR WILL PROBABLY FLY ON EARLY SPACE STA. AN ADVANCED ONE REQUIRING LSS MIGHT FLY 5 YEARS OR SO LATER.
C-5	GEOSTATIONARY PLAT-FORM DEMONSTRATION	1990	<1995	OVERLAPS C-6. PROBABLY A COMMERCIAL DEVELOPMENT
C-6	MULTI-SERVICE THIN ROUTE NARROWBAND PROGRAM	1988	>1995	LARGE APERTURE MAY BE FIRST USED ON ADVANCED DIRECT BROADCAST (DBS)
C-8	ORBITING DEEP SPACE RELAY STATION	>1990	1995	ADVANCED TDRS HIGHER PRIORITY CIRCA 1990
U-11	LARGE POWER MODULE	>1995	1999	MAY BE SOME HIGH POWER SPACE MANUFACTURING NEEDS BY THEN
U-13	SPACE POWER TECH-NOLOGY DEMO.	>1995	??	WILL PROBABLY BE EVOLUTIONARY —NO TECHNOLOGY DEMONSTRATION
S-14	PINHOLE SATELLITE	>1990		LSS PROBABLY NOT REQUIRED – RATIONALE?
S-15	CLOSE SOLAR ORBITER	>1995		PROBABLY CONVENTIONAL SIZE SPACECRAFT
L-3	SEARCH FOR EXTRATER-RESTRIAL INTELLIGENCE (SETI)	TBD		NEXT STEP IS GROUND-BASED TELESCOPES – MAYBE COULD USE A-16
T-14	ADVANCED ELECTRIC PROPULSION	>1995		NO MISSION IDENTIFIED FOR IT

Table 2.1.1-1. Future LSS Missions (Continued)

KEY	MISSION	SSTM DATE	REVISED DATE	REMARKS
AIAA IDENTIFIED MISSIONS				
AA-1	X-RAY OBSERVATORY (75 m DIA)	1995		APPEARS TO CONFLICT WITH AXAF MAYBE POST-2000
AA-2	LINEAR OPTICAL ARRAY (20 m DIA)	1995		SEEMS TO OVERLAP A-22 (THINNED APERTURE)
AA-3	OPTICAL ARRAY (100 m)	2000	1998	SAME AS A-22
AA-4	WAVE INJECTION WIRE (20 km LONG)	< 1995	< 1995	SIMPLE TETHER MISSION. DON'T SEE NEED FOR ADVANCED TECHNOLOGY
AA-5	SOIL MOISTURE (30 m ACTIVE)	1990	1982	CANDIDATE MISSION FOR SUN-SYNC. SPACE STATION
AA-6	SOIL MOISTURE (100 m PASSIVE)	1995	2000	SAME 100 m ANTENNA CAN SERVE BOTH AA-6 AND AA-7
AA-7	STORM CELL TRACKING (100 m DIA)	2000	2000	SAME 100 m ANTENNA CAN SERVE BOTH AA-6 AND AA-7
AA-8	NIGHT ILLUMINATOR REFLECTOR (100-300 m DIA)	< 1995		DON'T BELIEVE IT UNLESS SOME MUNICIPALITY FUNDS IT
MILITARY IDENTIFIED MISSIONS				
M-1	MEDIUM ALTITUDE PARABOLIC CYLINDER RADAR			VALID MILITARY MISSION
M-2	SYNCHRONOUS ALTITUDE ACTIVE LENS RADAR			VALID MILITARY MISSION
M-3	MEDIUM ALTITUDE TACTICAL SURFACE RECONNAISSANCE RADAR			VALID MILITARY MISSION
M-4	DISTRIBUTED ARRAY RADIOMETER SURVEILLANCE			VALID MILITARY MISSION
M-5	MEDIUM ALT. SPACE SURVEILLANCE RADAR	>1990	<1995	BEHIND SBSS ON DOD PRIORITY LIST
M-6	SPACE BASED LASER FOR ASAT	>1990	>1990	
M-7	SPACE BASED LASER FOR ABM	>1990	~2000	

It was observed that several of the missions could use the same type of spacecraft and the goals of other missions overlap. Therefore some of the missions were eliminated due to the commonality of their configurations or missions.

The published launch date estimates for some of the missions also appear to be too optimistic based on the technology readiness as demonstrated by ground tests and future STS flight tests. Therefore the estimated launch dates for some of the missions are revised as shown in the table. The need for these revisions are discussed further in subsection 2.1.8.

As a result of this further assessment of LSS missions, the revised LSS mission model shown in Table 2.1.1-2 was obtained. These missions, then, form the basis for identifying LSS technology development goals, TDM objectives and requirements.

Table 2.1.1-2. Revised LSS Mission Model

		MISSION	ESTIMATE LAUNCH*
NASA IDENTIFIED MISSIONS:	A-16	ORBITING SUBMILLIMETER TELESCOPE	EARLY 1990's
	A-17	LARGE AMBIENT DEPLOYABLE IR TELESCOPE	EARLY 1990's
	A-18	INFRARED INTERFEROMETER	>1995
	A-21	LARGE OPTICAL/UV TELESCOPE	>1995
	A-22	100 METER THINNED APERTURE TELESCOPE	>1995
	E-11	OCEAN RESEARCH (SYNTHETIC APERTURE RADAR)	1995
	C-5	GEOSTATIONARY PLATFORM DEMONSTRATION	<1995
	C-6	MULTI-SERVICE THIN ROUTE NARROWBAND PROGRAM	<1995
	C-8	ORBITING DEEP SPACE RELAY STATION	1995
	U-11	LARGE POWER MODULE	>1995
AIAA IDENTIFIED MISSIONS:	AA-3	OPTICAL ARRAY (100 m DIA)	1998
	AA-5	SOIL MOISTURE (30 m ACTIVE)	1992
	AA-6	SOIL MOISTURE (100 m PASSIVE)	2000
	AA-7	STORM CELL TRACKING, ACTIVE (100 m DIA)	2000
MILITARY IDENTIFIED MISSIONS:			
	M-1	MEDIUM ALTITUDE PARABOLIC CYLINDER RADAR	
	M-2	SYNCHRONOUS ALTITUDE ACTIVE LENS RADAR	
	M-3	MEDIUM ALT. TACTICAL SURFACE RECONNAISSANCE RADAR	
	M-4	DISTRIBUTED ARRAY RADIOMETER SURVEILLANCE	
	M-5	MEDIUM ALT. SPACE SURVEILLANCE RADAR	>1990
	M-6	SPACE BASED LASER FOR ASAT	>1990
	M-7	SPACE BASED LASER FOR ABM	>1990

*BEST CURRENT EST.

2.1.2 LSS Technology Development Goals

A detailed review of the spacecraft postulated for the missions listed in the revised mission model revealed the technology development goals listed in Table 2.1.2-1; these must be achieved to accomplish the desired missions.

The required size of the spacecraft leads to the first goal: to deploy large structures in space. Deployment may occur with several degrees of complexity: a) deployment of a complete spacecraft system including all subsystems (power, propulsion, control, etc.) required for autonomous spacecraft operation; b) deployment of structural modules to which subsystems and/or other structural modules may be attached in space, or c) deployment of structural members which are components of a large space structure to be assembled in space.

Table 2.1.2-1. LSS Technology Development Goals

- **DEMONSTRATE THE ABILITY TO:**
  - **DEPLOY LARGE SPACE SYSTEMS, STRUCTURAL ASSEMBLIES AND STRUCTURAL COMPONENTS IN SPACE**
  - **ASSEMBLE STRUCTURAL AND SUBSYSTEM COMPONENTS AND/OR ASSEMBLIES INTO A LARGE SPACE SYSTEM**
  - **MANUFACTURE OR FABRICATE STRUCTURAL COMPONENTS FROM RAW STOCK OR MATERIALS**
  - **MAINTAIN DYNAMICAL CONTROL OF THE STRUCTURE AND SYSTEM THROUGH ALL PHASES OF ASSEMBLY AND OPERATION.**

The second goal follows from the first in that the deployable structural components or modules must be assembled into a complete spacecraft. This assembly process includes the installation of subsystem components such as antenna reflecting surfaces and feed systems, optical mirrors, control systems, propulsion systems, data systems, etc.

The construction of very large spacecraft leads to the third goal: space fabrication. Current design studies show that deployable and assemblable spacecraft reach the volume limits of the shuttle payload bay and not the weight limit. To provide a more economical solution to the construction of very large structures, it may be advantageous to fabricate lightweight structural members from raw stock which can be densely packaged for delivery to space. The fabrication facility could be delivered and left on orbit during contruction and subsequent revisits would be used to supply additional raw stock. The resulting structural components would then be assembled to form the large space structure.

The fourth goal points out the necessity to provide control and stability throughout the deployment, construction or assembly process. The control system of the construction base, whether it is the shuttle, an unmanned platform or a space station, must be capable of providing stability to assure safety and structural integrity during all phases of construction and operation.

2.1.3 Technology Development Ground Tests

For many years, NASA and the aerospace industry have been developing the technology and techniques necessary to construct large space structures. Since these deployable or assemblable structures will operate in a near zero g environment, ground testing methods which simulate the operational environment are required for testing both the structure and the human involvement in assembling them. Individual ground tests for LSS application are too numerous to be identified in this study. Instead, various types of ground tests used to demonstrate LSS technology developments will be discussed. Examples of ground testing shown in Figure 2.1.3-1 identify the various testing techniques used for LSS testing.

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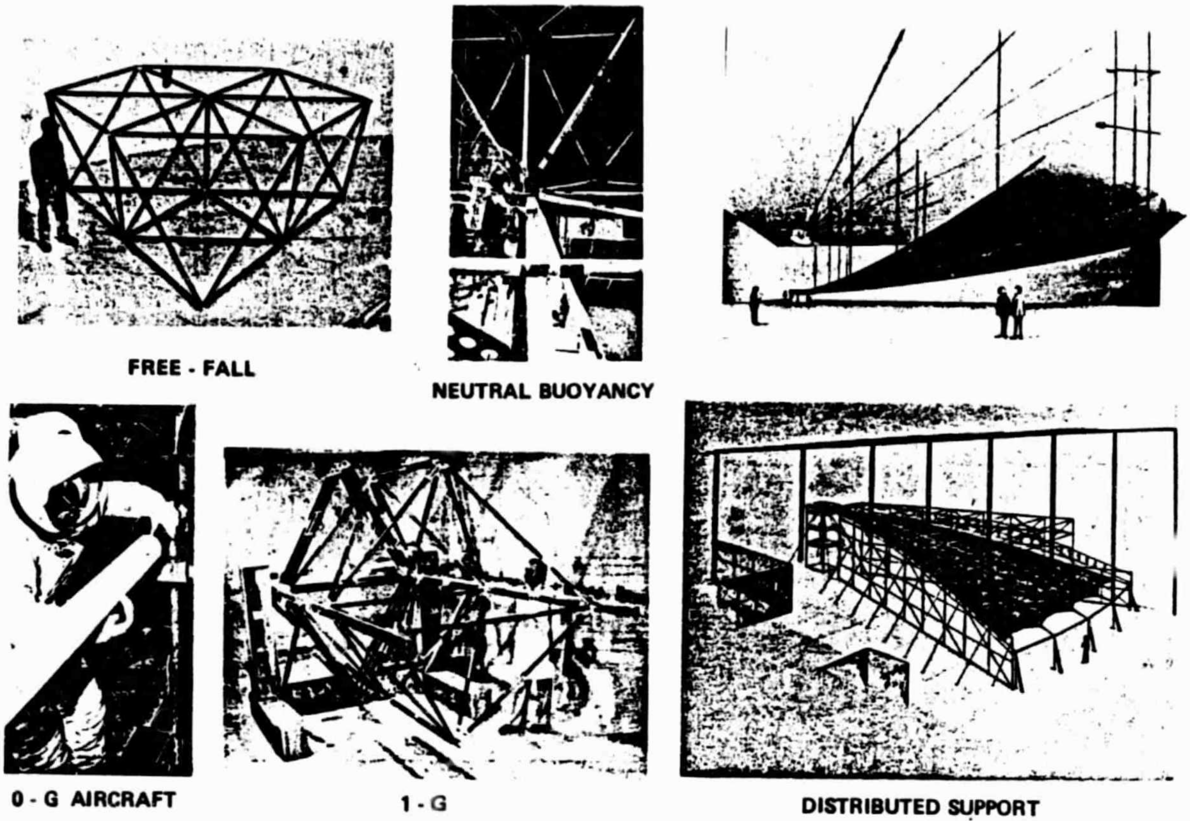

Figure 2.1.3-1. LSS Technology Ground Tests

The mechanics and procedures for deploying some structural components such as linear truss structures which can support their own weight can be functionally demonstrated in a 1-g environment. These tests usually use a portion of the full structure which is sufficient to demonstrate the deployment and retraction mechanisms and joints.

Deployment of planar (or parabolic) truss structures has been demonstrated using free-fall techniques both in air and in a vacuum. With the short test times available, the deployment must be rapid and essentially uncontrolled (except for joint friction and deployment spring design). Tests of bare truss structures and trusses with reflective membranes attached have been performed.

Testing of large flexible structures which cannot support their own weight on Earth requires multiple supports to distribute their weight. Deployment can be functionally demonstrated using moving supports which follow the structure as it deploys. Dynamic testing of these structures, however, is limited due to the influence of the support system.

Human involvement in the construction of large space structures can be demonstrated in several ways. Assembly operations in 1-g have been used to evaluate structural assembly tasks using proposed work station concepts. Simple assembly and alignment tasks have been demonstrated in aircraft which fly a zero-g trajectory for short periods of time. Longer duration assembly tasks are conducted in a neutral buoyancy simulator (NBS). Test subjects in EVA suits are weighted and the structural components are equipped with flotation resulting in neutral buoyancy in a large water tank. With the exception of drag and apparent mass effects, the tests provide a close simulation of on-orbit assembly operations. Future correlation of in-space and neutral buoyancy task times will provide the data necessary to make the NBS a more valuable tool for the determination of orbital operations procedures and timelines.

Numerous other ground tests on structural and other subsystem components and technologies (deployable and assemblable joints, adjustment mechanisms, deployment mechanisms, control systems, figure sensing and adjustment techniques, thermal control systems, materials, etc.) are being conducted at NASA and throughout industry which contribute to the many facets of LSS development. Many of these developments are documented in the annual LSST technology reviews and in various government sponsored contract reports.

2.1.4 Technology Development Flight Test Plans

Following ground tests, analyses and simulations, the techniques required for constructing large space structures must be demonstrated in a space environment. Several Shuttle flight tests have been identified which will help to demonstrate LSS concepts and

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techniques.

- o Solar Array Flight Experiment (SAFE I)
- o Space Construction Experiment (SCE) or (MAST)
- o Structural Assembly Demonstration Experiment (SADE)
- o Antenna Flight Experiment

These flight tests are shown graphically in Figure 2.1.4-1 and are described briefly in subsequent paragraphs.

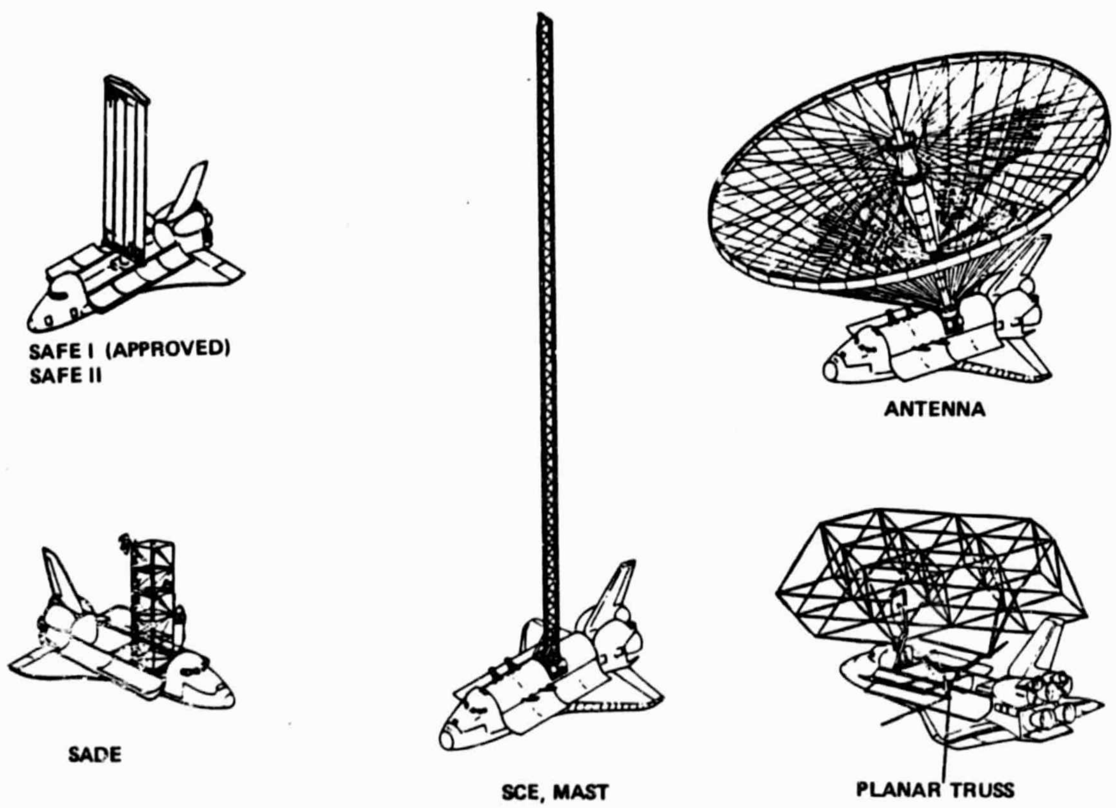

Figure 2.1.4-1. Planned LSS Technology Flight Tests for Shuttle

Four of the proposed orbiter flight tests have been studied by various agencies in sufficient detail to identify ground test schedules and launch dates as shown in Figure 2.1.4-2. The solar array flight experiment (SAFE I) is the only flight test which has been approved at this time. The others will be valuable in demonstrating technology required for LSS by contributing to a logical progression of development tests.

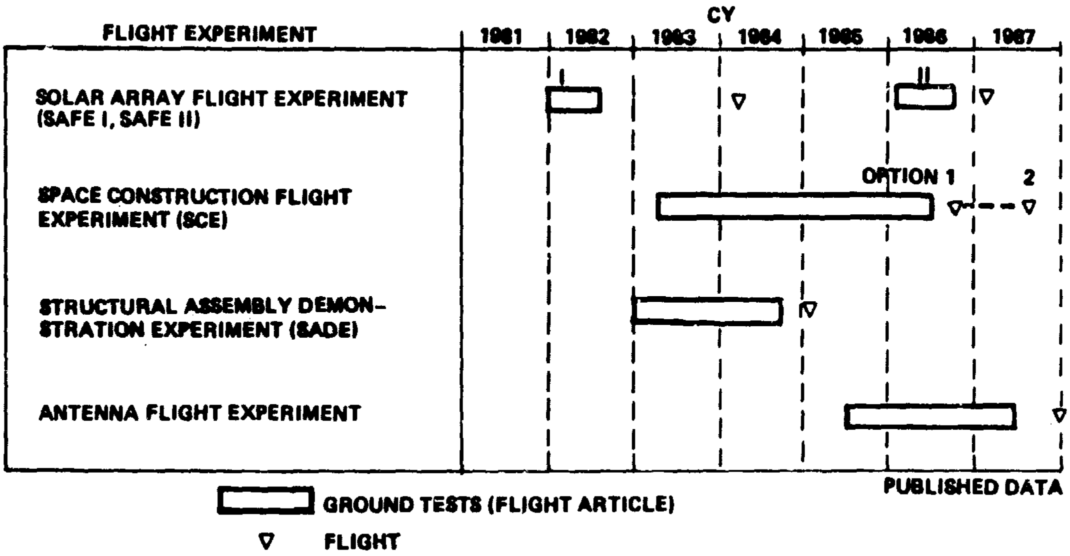

Figure 2.1.4-2. Shuttle Flight Test Schedule

Solar Array Flight Experiment (SAFE I)

The solar array flight experiment (SAFE I) [34, 35] consists of four experiments. The purpose of these experiments is to demonstrate the flight readiness of lightweight solar array technology for solar electric propulsion and other payload power applications. The early availability of this experiment and its basic large space structure characteristics make it a logical candidate to demonstrate other disciplines critical to large space structures. These demonstrations form the basis for three other solar array experiments, two in remote sensing and one in control.

The characterisitics of the solar array which are generically similar to large space structures are:

1. Large size
2. Mechanical complexity of its extendable/retractable mast
3. The inability to perform dynamic tests in earth atmosphere and one g, due to size, air damping dominance on the blanket, and structural instability in one g
4. Low natural frequencies

The experiment objectives are to:

1. Demonstrate the capability to deploy and retract the array in the space environment
2. Demonstrate array structural integrity for Shuttle launch and reentry
3. Measure and observe extended array dynamic behavior
4. Correlate observed thermal and electrical performance with predicted performance
5. Qualify flexible fold solar array technology for use on Shuttle payloads.

The solar array wing has 84 flexible solar cell panels which are accordion folded into or out of a solar array blanket containment box when the solar array wing retracts or extends. These panels are joined by hinges located along the long dimension of the panel. A coilable continuous longeron extension mast, located behind the blanket, is used to provide the motion which deploys and stows the blanket. The mast which is 32 m long (extended) and 37.3 cm in diameter is coiled into a canister which is 1.52 m x 40.6 cm when the blanket is retracted. The array preload provides compressional force upon the stowed solar array blanket to protect the solar cell assemblies against vibration during launch or reentry operations of the Shuttle. The experiments are presently being developed by LMSC for MSFC with a planned launch of SAFE I in 1984 and SAFE II in 1987.

Structural Assembly and Demonstration Experiment (SADE)

During the past several years the large space structures work at the Marshall Space Flight Center has followed the normal program of planning exercises, analysis, and contractor studies followed by the ground test of hardware components and systems. As the next step in this scheme a Structural Assembly and Demonstration Experiment (SADE) [36-38] is proposed as a flight test to corroborate these previous steps and to demonstrate the space construction of a simple truss structure approximately 100 feet in length. It uses both deployable and erectable construction methods and will be built in the Shuttle bay where it remains throughout the flight. The SADE is scheduled to fly in 1985.

The purpose of SADE is first to demonstrate that the Shuttle is a suitable base for space construction; this includes a test of the Shuttle's control system to determine its performance when a long attached truss or beam is extended from the bay. Examples of Shuttle related systems that will receive special attention are the RMS, the lighting system, and the crew assembly capabilities. Further objectives are to determine the extent to which the assembly results from the Neutral Buoyancy Simualtor can be used to forecast the results of space assembly, and, finally, to validate the SADE truss design by measuring the performance of the deployment, the special connectors, and the assembly methods.

Space Construction Experiment (SCE or MAST)

A deployable beam experiment labeled Space Construction Experiment (SCE) [39-42] or MAST [43] has been proposed as a Shuttle based experiment contributing to the development of LSS technology.

A number of objectives are incorporated in a single experiment concept. The Shuttle has inherent capabilties that are applicable to the construction of large space systems. If construction with deployable structures is to be accomplished, the Orbiter digital autopilot (DAP) must be able to control the structure during buildup. Large deployable structures which are essential to the development of large space systems must be understood in terms of system identification and modal damping. The simple linear structure will permit evaluation in flight and correlation with ground tests and simulations and may be applicable to the feed mast of a large antenna. It also may be possible to incorporate elements of LSS control systems in anticipation of a more complex experiment such as a free-flyer.

The basic experiment concept involves three classes of activity in the process of meeting the experiment objectives. A single element deployed from the cargo bay of the Shuttle can evaluate construction operations during buildup of the experiment configuration. Control during Orbiter maneuvers will evaluate the performance of the Orbiter DAP. Dynamic excitation of the structure identifies system characteristics for correlation with ground test and simulations. Reference 40 indicates that this experiment could be flown in 1986.

Antenna Flight Experiment

Studies conducted by government agencies and industry have identified the feasability of deploying large antenna systems (30-100 meter diameter) from the Shuttle [44]. These systems would be packaged in the Shuttle payload bay and automatically deployed on orbit. Flight experiments envisioned for FY'88 and FY'90 will demonstrate the technologies involved in large antenna system deployment. Following on-orbit operations, the antennas would be repackaged and returned to Earth.

Planar Truss Experiment

The last Shuttle flight experiment depicted in Figure 2.1.4-1 is the assembly or deployment of a portion of a large planar truss structure. This experiment would be a logical progression of ground tests in neutral buoyancy simulators leading up to the construction of even larger structures in space.

2.1.5 Space Shuttle Accommodations and Constraints

The decision to conduct technology demonstration missions from the Shuttle or at the Space Station requires a knowledge of the accommodations available on the Shuttle. These have been documented in NASA CR 160861, "Shuttle Considerations for the Design of Large Space Structures" [45]. This document is a compendium of Shuttle capabilities, constraints and guidelines which have been abstracted from currently available documents generated by NASA, Rockwell International, and by other NASA contractors. The document includes summaries of significant results from experience gained in Shuttle integration activities and from an extensive study of space construction system analyses. Essentially no new technical data were generated, but an attempt was made to provide updated information concerning Orbiter systems and to discuss potential new Shuttle hardware and procedures concepts currently being studied.

Figure 2.1.5-1 identifies a few of the Shuttle constraints which must be considered by LSS designers: payload volume, weight, center of gravity, etc. Additional constraints such as visibility and RMS reach limits influence the design of payload manipulation and assembly procedure while on orbit.

2.1.6 Early Space Station Capabilities

Although a Space Station configuration has yet to be finalized, the results of previous Space Station and platform studies throughout the industry have identified capabilities envisioned to be available [8, 9, 10, 45]. These capabilities itemized in Table 2.1.6-1 include support equipment, interfaces, data management, power, thermal rejection and work space. In addition, the skill requirements of the crew for a variety of tasks have

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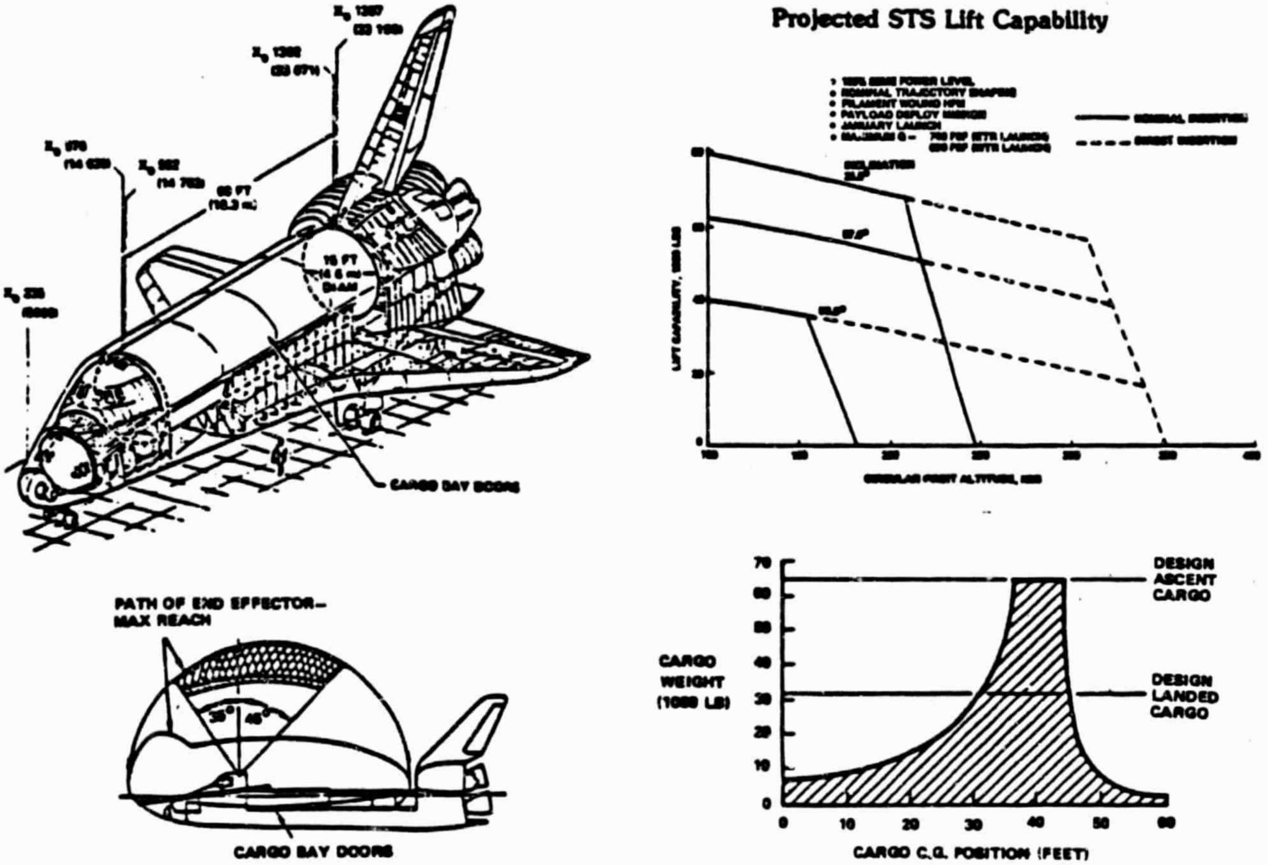

Figure 2.1.5-1. Space Shuttle Constraints

Table 2.1.6-1. Early Space Station Capabilities

CREW SIZE: MINIMUM OF 3

CREW SKILLS:
- IVA OPERATOR (RMS)
- EVA OPERATOR (RMS)
- EVA OPERATOR (EVA WORKSTATION)
- TEST AND CHECKOUT ENGINEER
- ELECTRICAL/MECHANICAL ENGINEER
- PROPELLANT/FUEL SPECIALIST
- FLIGHT CONTROLLER/SYSTEMS ENGINEER
- TMS OPERATOR

SUPPORT EQUIPMENT:
- TELEOPERATOR MANEUVERING SYSTEM (TMS)
- RMS OR CHERRYPICKER
- STORAGE FACILITY
- LIGHTING
- REMOTE MONITORING (TV)
- LOGISTICS MODULE

INTERFACES:
- ORBITER-COMPATIBLE DOCKING/BERTHING PORT
- LSS ATTACHMENT FIXTURE(S)
- UTILITIES (POWER, CRYO FLUIDS (?), AIR, ETC.)
- DATA (HARDWIRE, FIBEROPTICS, TELEMETRY)

DATA MANAGEMENT:
- DATA RELAY ANTENNAS
- DATA HANDLING, PROCESSING, COMPACTING, ETC.

POWER: AS NEEDED UP TO 10 KW

THERMAL REJECTION: TBD

WORK SPACE:
- PAYLOAD CONTROL CENTER
- CONSTRUCTION ENVELOPE—TBD

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been identified in broad terms. Each crew member will not be required to possess all of these skills since several crew members will be present at the space station.

2.1.7 Site Selection for Technology Development Demonstrations

The list of technology development goals identified in subsection 2.1.2 were expanded into a more detailed list of LSS technology tasks which must be demonstrated to accomplish the stated goals. The current ground tests and planned flight tests were then examined to identify the testing methods being employed to demonstrate each of these LSS technology tasks. Table 2.1.7-1 presents the results of this comparison and highlights those areas which require additional flight testing to demonstrate required LSS technology.

Table 2.1.7-1. Current LSS Technology Development Testing

LSS TECHNOLOGY TASK	GROUND TESTS				CAND. STS FLT TESTS				
	NEUTRAL BUOYANCY	FREE FALL	DISTRIBUTED SUPPORT	1-G	SAFE*	SCE, MAST	SADE	ANTENNA	ADDITIONAL FLIGHT TESTS REQUIRED
DEPLOY LARGE SOLAR ARRAYS				X	X			X	
DEPLOY LARGE LINEAR STRUCTURES	X		X	X	X	X	X	X	
DEPLOY LARGE AREA PLANAR TRUSS STRUCTURES		X	X	X					←
DEPLOY LARGE ANTENNA SYSTEMS			X					X	←
ASSEMBLE LARGE TRUSS STRUCTURES	X			X			X		←
JOIN DEPLOYABLE MODULES/MEMBERS				X			X		←
ASSEMBLE PRECISION OPTICAL SYSTEMS				X					←
INSTALL SUBSYSTEMS & UTILITIES	X			X		X	X		
INSTALL LARGE AREA MEMBRANE SYSTEMS				X					←
FABRICATE LINEAR STRUCTURAL MEMBERS				X					←
PROVIDE STABILITY THROUGHOUT CONSTRUCTION					X	X	X	X	
DEMONSTRATE STRUC ACCURACY & ALIGNMENT			X	X				X	←
PROVIDE PRECISION SURFACE CONTROL			X	X				X	←
DETERMINE DYNAMIC BEHAVIOR OF LSS		X	X	X	X	X	X	X	
DETERMINE THERMAL RESPONSE/CONTROL OF LSS				X	X		X		
DETERMINE STRUCTURE/CONTROL INTERACTION			X	X	X	X	X	X	
DEMONSTRATE PRECISION POINTING (S/C SUBSYS)				X				X	←
DEMONSTRATE DOCKING/JOINING VIA TMS									←
DEMONSTRATE STRUC DAMPING AUGMENTATION			X	X	X	X	X		
EVALUATE SYSTEM IDENTIFICATION TECHNIQUES			X	X	X	X			
VERIFY ANALYTICAL PREDICTIONS			X	X	X	X	X	X	
EXPLORE MAN'S ROLE & CAPABILITIES IN SPACE	X	X		X		X	X		

*SCHEDULED

Using the Shuttle accommodations and constraints identified in subsection 2.1.5 and the capabilities of an early Space Station enumerated in subsection 2.1.6, the flight tests required to demonstrate the LSS technology tasks were divided into three categories:

a. Tests that are best suited for using the Shuttle. Examples are SAFE: the Lockheed foldable solar array which will be deployed and tested for structural dynamics, and SADE: the deployment, assembly and test of a linear truss structure.

b. Demonstrations that could be done on Shuttle sortie flights but that would be enhanced by being performed at a Space Station. Examples include LSS tests that would benefit by having more time than that available using the Shuttle. Another example would be where more than one demonstration test could be performed on the same test article if it could be left at a Space Station while results of a previous test were being analyzed.

c. Tests that require a Space Station. An example would be demonstration of the capability to assemble a very large diameter parabolic antenna. This demonstration would require support equipment and on-orbit time beyond Shuttle capabilities.

The results of this sorting are shown in Table 2.1.7-2. Many tests would benefit from a Space Station, particularly if several could be combined. The LSS technology tasks that require a Space Station are those associated with the construction of large antennas and optical systems which involve long construction times and which require lengthy adjustment and checkout tasks to be performed in space. More detailed descriptions of factors which point out the need for a Space Station (support equipment, accommodations, timelines, etc.) will be presented in subsequent sections.

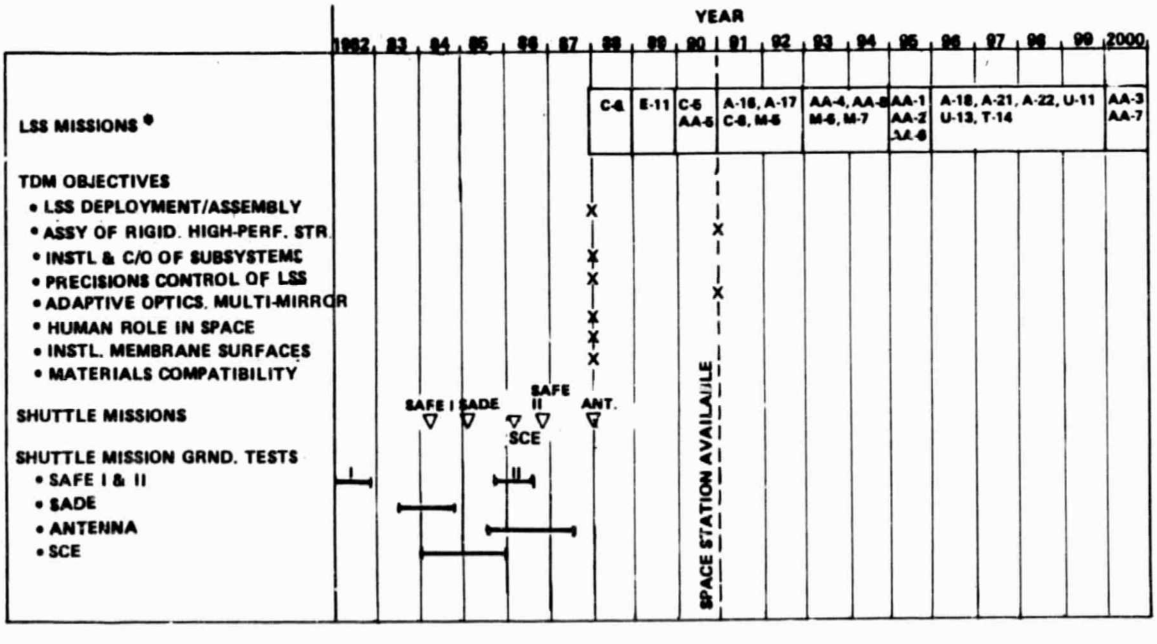
2.1.8 Integrated Time-Phased Scenario

The results of the review of future mission plans, ground tests, Shuttle tests and LSS technology development goals were combined to produce the integrated time-phased scenario of planned missions and development tests shown in Figure 2.1.8-1. The LSS

Table 2.1.7-2. LSS Technology Development Test Locations

LSS TECHNOLOGY TASK	FLIGHT TESTS* A	B	C
DEPLOY LARGE SOLAR ARRAYS	X		
DEPLOY LARGE LINEAR STRUCTURES	X		
DEPLOY LARGE AREA PLANAR TRUSS STRUCTURES		X	
DEPLOY LARGE ANTENNA SYSTEMS			X
ASSEMBLE LARGE TRUSS STRUCTURES			X
JOIN DEPLOYABLE MODULES/MEMBERS	X		
ASSEMBLE PRECISION OPTICAL SYSTEMS			X
INSTALL SUBSYSTEMS & UTILITIES		X	
INSTALL LARGE AREA MEMBRANE SYSTEMS			X
FABRICATE LINEAR STRUCTURAL MEMBERS		X	
PROVIDE STABILITY THROUGHOUT CONSTRUCTION		X	
DEMONSTRATE STRUC ACCURACY & ALIGNMENT		X	
PROVIDE PRECISION SURFACE CONTROL		X	
DETERMINE DYNAMIC BEHAVIOR OF LSS		X	
DETERMINE THERMAL RESPONSE/CONTROL OF LSS		X	
DETERMINE STRUCTURE/CONTROL INTERACTION		X	
DEMONSTRATE PRECISION POINTING (S/C SUBSYS)		X	
DEMONSTRATE DOCKING/JOINING VIA TMS		X	
DEMONSTRATE STRUC DAMPING AUGMENTATION		X	
EVALUATE SYSTEM IDENTIFICATION TECHNIQUES		X	
VERIFY ANALYTICAL PREDICTIONS		X	
EXPLORE MAN'S ROLE & CAPABILITIES IN SPACE		X	

* A—TESTS SUITABLE FOR SHUTTLE
B—TEST WHICH WOULD BENEFIT FROM TESTING AT A SPACE STATION
C—TESTS WHICH REQUIRE A SPACE STATION



* PRESENT LSS MISSION PLANS (SEE TABLE 2.1.1-1. FOR MISSION CODES)

Figure 2.1.8-1. Time-Phased Scenarios of LSS Missions

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mission codes are from the mission model shown in Table 2.1.1-1. Included in the figure is a list of TDM objectives and the year when each objective is required for specific missions. Based on present SSTM data, the need to accomplish many of the TDM objectives occurs before the technology will be demonstrated by Shuttle flight tests and all are required before a Space Station will be operational. Therefore, the mission model was re-evaluated and a revised launch schedule for LSS missions was developed which would allow the Shuttle flight tests to occur in time to influence the design of LSS missions. The Space Station will also be available by then for deployment, assembly, and checkout activities. The revised scenario is shown in Figure 2.1.8-2.

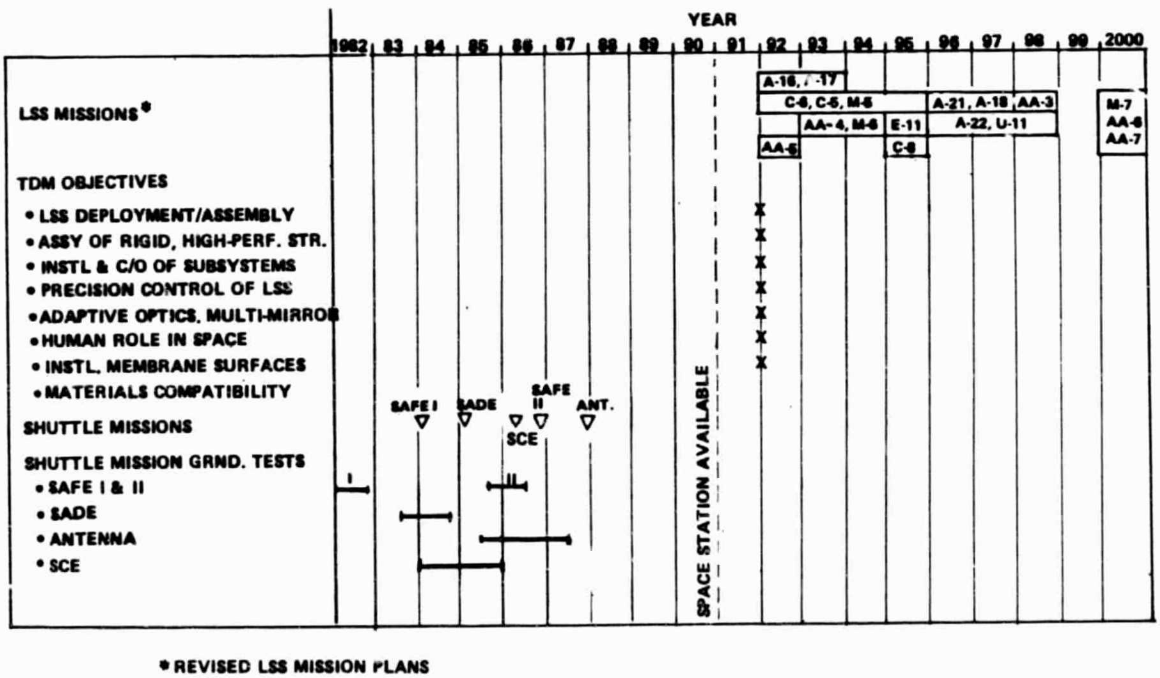

Figure 2.1.8-2. Revised Time-Phased Scenario of LSS Missions

2.2 MISSION OBJECTIVES

The task of developing the evolutionary technology plan in Section 2.1 identified the logical progression of ground and Shuttle flight tests which contribute to LSS technology development. It also identified further flight testing required to augment those tests already planned along with the recommended location of those tests. The results of this task lead to the identification of the following mission objectives for TDMs performed on the Space Station:

- o Space deployment or assembly of large space structures
- o Space assembly of rigid, high-precision complex structures
- o Installation and checkout of subsystems on LSS
- o Installation of membrane surfaces on large aperture antennas
- o Precision control of LSS (pointing, surface)
- o Adaptive optics; assembly, test, calibration and control of large multi-mirror surface
- o Demonstrate man's role and capabilities in space
- o Materials development

These objectives augment currently planned Shuttle mission objectives, provide a logical progression of technology development, and provide a basis for deriving mission requirements.

2.3 MISSION REQUIREMENTS

Requirements for each of the eight mission objectives are itemized in Table 2.3-1. The requirements are written at a relatively high level due to the conceptual nature of the missions but are directed toward developing experiment hardware designs and operational

Table 2.3-1. Technology Development Mission Requirements

OBJECTIVE	REQUIREMENTS
SPACE DEPLOYMENT OR ASSEMBLY OF LARGE SPACE STRUCTURES	• PROVIDE STRUCTURAL ELEMENTS/MODULES (PAYLOAD) • PROVIDE MEANS TO OFFLOAD TEST HARDWARE FROM ORBITER • PROVIDE STORAGE LOCATION • PROVIDE FIXTURE TO HOLD TEST ARTICLE WHILE BEING DEPLOYED/ ASSEMBLED • PROVIDE WORK STATION FOR EVA ASTRONAUT(S) • PROVIDE MEANS TO MANIPULATE AND JOIN ELEMENTS/MODULES • PROVIDE LIGHTING/VISIBILITY • PROVIDE MEANS TO MEASURE STRUCTURAL ALIGNMENT/ACCURACY • PROVIDE MEANS TO DETERMINE STATIC, DYNAMIC AND THERMAL CHARACTERISTICS
SPACE ASSEMBLY OF RIGID, HIGH-PRECISION COMPLEX STRUCTURES	• PROVIDE STRUCTURAL ELEMENTS/MODULES (PAYLOAD) • PROVIDE MEANS TO OFFLOAD TEST HARDWARE FROM ORBITER • PROVIDE STORAGE LOCATION • PROVIDE FIXTURE TO HOLD TEST ARTICLE WHILE BEING DEPLOYED/ ASSEMBLED • PROVIDE WORK STATION FOR EVA ASTRONAUT(S) • PROVIDE MEANS TO MANIPULATE AND JOIN ELEMENTS/MODULES • PROVIDE LIGHTING/VISIBILITY • PROVIDE MEANS TO MEASURE STRUCTURAL ALIGNMENT/ACCURACY • PROVIDE MEANS TO DETERMINE STATIC, DYNAMIC AND THERMAL CHARACTERISTICS • PROVIDE MEANS TO ADJUST STRUCTURAL ALIGNMENT (PAYLOAD) • PROVIDE MEANS TO "RIGIDIZE" JOINTS (PAYLOAD)
INSTALLATION AND CHECKOUT OF SUBSYSTEM ON LSS	• PROVIDE SUBSYSTEMS (PAYLOAD) • PROVIDE MEANS TO OFFLOAD FROM ORBITER • PROVIDE STORAGE LOCATION • PROVIDE STRUCTURAL ARTICLE ON WHICH TO INSTALL SUBSYSTEMS • PROVIDE MEANS TO MANIPULATE AND ATTACH SUBSYSTEMS MODULES • PROVIDE MEANS TO ROUTE AND ATTACH UTILITIES ALONG STRUCTURE • PROVIDE WORK STATION FOR EVA ASTRONAUT(S) • PROVIDE LIGHTING/VISIBILITY • PROVIDE TEST EQUIPMENT FOR SUBSYSTEM CHECKOUT AND DIAGNOSTIC TESTING • PROVIDE SPARES/TOOLS FOR REPLACEMENT/REPAIR
INSTALLATION OF MEMBRANE SURFACES ON LARGE APERTURE ANTENNAS	• PROVIDE PACKAGED MEMBRANE SEGMENTS (PAYLOAD) • PROVIDE MEANS TO OFFLOAD FROM ORBITER • PROVIDE STORAGE LOCATION • PROVIDE MEANS TO TRANSPORT AND POSITION PACKAGED MEMBRANE • PROVIDE MEANS TO MAKE INITIAL ATTACHMENT • PROVIDE MEANS TO DEPLOY MEMBRANE • PROVIDE MEANS TO MAKE FINAL ATTACHMENT • PROVIDE MECHANISM TO ADJUST MEMBRANE TENSION (PAYLOAD) • PROVIDE ELECTRICAL CONNECTIONS IF REQUIRED (PAYLOAD) • PROVIDE SURFACE ACCURACY MEASUREMENTS AND TECHNIQUES • PROVIDE LIGHTING/VISIBILITY • PROVIDE SURFACE ADJUSTMENT CAPABILITY (PAYLOAD)

Table 2.3-1. Technology Development Mission Requirements (Continued)

OBJECTIVE	REQUIREMENTS
PRECISION CONTROL OF LSS (POINTING, SURFACE)	• PROVIDE LSS (PAYLOAD) • PROVIDE SENSORS TO MEASURE POINTING/SURFACE ACCURACY (PAYLOAD) • PROVIDE ACTUATORS TO PROVIDE FORCE/TORQUE (PAYLOAD) • PROVIDE COMPUTER HARDWARE/SOFTWARE (PAYLOAD) • PROVIDE MEANS TO MONITOR SYSTEM RESPONSE AND PERFORMANCE • PROVIDE DATA STORAGE AND ANALYSIS TOOLS • PROVIDE MEANS TO CHANGE/MODIFY CONTROL PARAMETERS (PAYLOAD)
ADAPTIVE OPTICS; CONTROL OF LARGE MULTI-MIRROR SURFACE	• PROVIDE SEGMENTED MIRROR SURFACE AND ASSOCIATED SUPPORT STRUCTURE (PAYLOAD) • PROVIDE FIXTURE TO HOLD TEST ARTICLE • PROVIDE SENSORS AND ACTUATORS • PROVIDE SURFACE ACCURACY MEASUREMENT EQUIPMENT AND TECHNIQUES • PROVIDE COMPUTER HARDWARE/SOFTWARE (PAYLOAD)
DEMONSTRATE MAN'S ROLE AND CAPABILITIES IN SPACE	• PROVIDE IVA CONTROL STATIONS FOR RMS AND TMS • PROVIDE EVA SUITS AND ECLSS • PROVIDE EVA WORK STATION • PROVIDE HAND-HOLDS AND FOOT RESTRAINTS • PROVIDE LIGHTING/VISIBILITY • PROVIDE TOOLS AND HANDLING EQUIPMENT • PROVIDE STRUCTURAL ATTACHMENTS/HOLDDOWNS • PROVIDE EVA CONTROL STATION FOR RMS
MATERIALS DEVELOPMENT	• PROVIDE MATERIALS SPECIMENS FOR EVALUATION (PAYLOAD) • PROVIDE SPACE ENVIRONMENT EXPOSURE FACILITY • PROVIDE FOR A VARIETY OF EXPOSURES AND ORIENTATIONS • PROVIDE MONITORING, PLACEMENT AND RETRIEVAL OF TEST SPECIMENS • PROVIDE LIGHTING/VISIBILITY • PROVIDE SMALL SPECIMEN AIRLOCK • PROVIDE FACILITY FOR MATERIAL PROPERTIES TESTING AND EVALUATION

procedures. Also considered in the definition of mission requirements are crew capabilities and utilization factors, mission duration and procedures, and safety. Requirements for interacting or interfacing technologies such as controls, thermal control, data management, EC/LS, etc. are also considered in the development of TDM requirements.

Many of the requirements are seen to be common to a number of objectives. Figure 2.3-1 shows a matrix of requirements vs. objectives which was created to show this commonality. Requirements for each of the eight LSS mission objectives are shown as the column headings on this figure. After identifying the primary requirements for each objective, it was evident that other requirements were of a secondary nature. These secondary requirements for each objective are indicated by circles in this array.

	REQUIREMENTS																			
TDM OBJECTIVE	TEST ARTICLE(S)	MEANS TO OFFLOAD FROM STS	STORAGE LOCATION	ATTACHMENT FIXTURE	EVA WORK STATION	SPACE STATION RMS	LIGHTING/VISIBILITY	MEASUREMENT DEVICES	SYSTEM RESPONSE MEAS.	ADJUSTMENT TECHNIQUES	"RIGIDIZE" JOINTS	ROUTING & ATTACHMENT DEVICE	SPARES AND TOOLS	DEPLOYMENT AIDS	ACTUATORS	DATA ANALYSIS/STORAGE	IVA WORK STATION	HAND-HOLDS, FOOT RESTRAINTS	EVA SUITS, ECLSS	SMALL SPECIMEN AIRLOCK
SPACE DEPLOYMENT OR ASSEMBLY OF LSS	•	•	•	•	•	•	•	•	•				O	O			O	O	O	
ASSEMBLY OF RIGID, HIGH-PRECISION STRUCT.	•	•	•	•	•	•	•	•	•	•	•		O					O	O	
INSTALLATION & CHECKOUT OF SUBSYSTEMS	•	•	•	O	•	•	•	•	•			•	•			O		O	O	
INSTALLATION OF MEMBRANE SURFACES	•	•	•	O	O	•	•	•		•		•	O	•				O	O	
PRECISION CONTROL OF LSS	•							•	•	•					•	•	O			
ADAPTIVE OPTICS; CONTROL OF MULTI-MIRROR SURFACE	•			•				•	•	•					•	•				
DEMONSTRATE MAN'S ROLE AND CAPABILITIES	•	O	O	•	•	O	•	O	O	O		O	•	O		O	•	•	•	O
MATERIALS DEVELOPMENT	•	O	•	•		•	•	•		•					•	•	•	O	O	•

• PRIMARY O SECONDARY

Figure 2.3-1. Commonality of TDM Requirements

3.0 DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS

The mission objectives and requirements identified in the previous section were used to define candidate technology development missions. Operations analyses were performed on these missions and Space Station accommodation needs were then identified.

3.1 Mission Conceptual Designs

The first step in defining TDMs was to prioritize the objectives identified in Section 2.2 and to combine them where possible to create missions of high technical and economic benefit. Four technology development missions were identified which will satisfy this prioritization and technical need. System level trade studies were performed to determine a specific configuration for each TDM followed by more detailed conceptual designs.

3.1.1 Prioritization and Combination of Objectives

A ranking of mission objectives was performed considering three topics: (1) applicability of the objective to a multiple number of missions, (2) relative timing of the need for specific technology developments, and (3) technology readiness. The ranking is shown in Figure 3.1.1-1 and indicates that LSS deployment/assembly is the highest priority objective followed closely by precision control and installation and checkout of subsystems.

The four TDMs selected were based on this ranking and the combination of several objectives in each mission. These TDMs fall into three general categories of missions: a

OBJECTIVE	APPLICATION TO MULTIPLE MISSIONS	RELATIVE TIMING OF THE NEED	TECH. READINESS ASSESSMENT (1990)	TOTALS	RANKING
LSS DEPLOYMENT/ASSEMBLY	1	1	6	8	1 (HIGHEST PRIORITY)
ASSEMBLY OF RIGID, HIGH-PRECISION COMPLEX STRUCTURES	6	2	4	12	4
INSTALLATION AND CHECKOUT OF SUBSYSTEMS ON LSS	2	4	5	11	3
PRECISION CONTROL OF LSS	3	3	3	9	2
INSTALLATION OF MEMBRANE SURFACES ON LARGE APERTURE ANTENNA	7	8	2	17	7
ADAPTIVE OPTICS; CONTROL OF LARGE MULTI-MIRROR SURFACE	8	7	1	16	5
DEMONSTRATE MAN'S ROLE IN SPACE	4	5	8	17	6
MATERIALS DEVELOPMENT	5	6	7	18	8

Figure 3.1.1-1. Ranking of TDM Objectives

large deployable truss structure, a large parabolic or spherical reflector or antenna and a high precision optical system.

3.1.2 Technology Development Mission Designs

It was recognized that programmatic as well as economic benefits could be realized if several objectives could be demonstrated using a common configuration; if the TDMs could be used to demonstrate technology objectives which interact with large space structures; and if the resulting configuration could provide a useful tool for operational functions or for scientific measurements following its use as a large space structures TDM. With these goals in mind, the four technology development mission (TDM) configurations were conceptually designed.

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TDM Configuration LSS-1: Construction and Storage Facility

Since most mission objectives require a storage location for structure, subsystems and other equipment and a location for assembly and checkout of spacecraft, the construction and storage facility shown in Figure 3.1.2-1 was chosen as a TDM configuration. It consists of a deployable truss platform attached to a transfer tunnel located at a docking/berthing port on a Space Station module. The figure shows the overall dimensions of the construction/storage facility and its relationship to a typical Space Station module. The platform could be oriented so that two transfer tunnels could be used for support. Additional bracing could be installed between the platform and Space Station module to provide additional stiffness and load carrying capability. A pair of rails supported by truss members shown in the end view will duplicate the orbiter bay longerons for the storage of large modules delivered to the Space Station. Compartments could be installed within the truss members to provide storage for small items such as tools, hold down mechanisms,

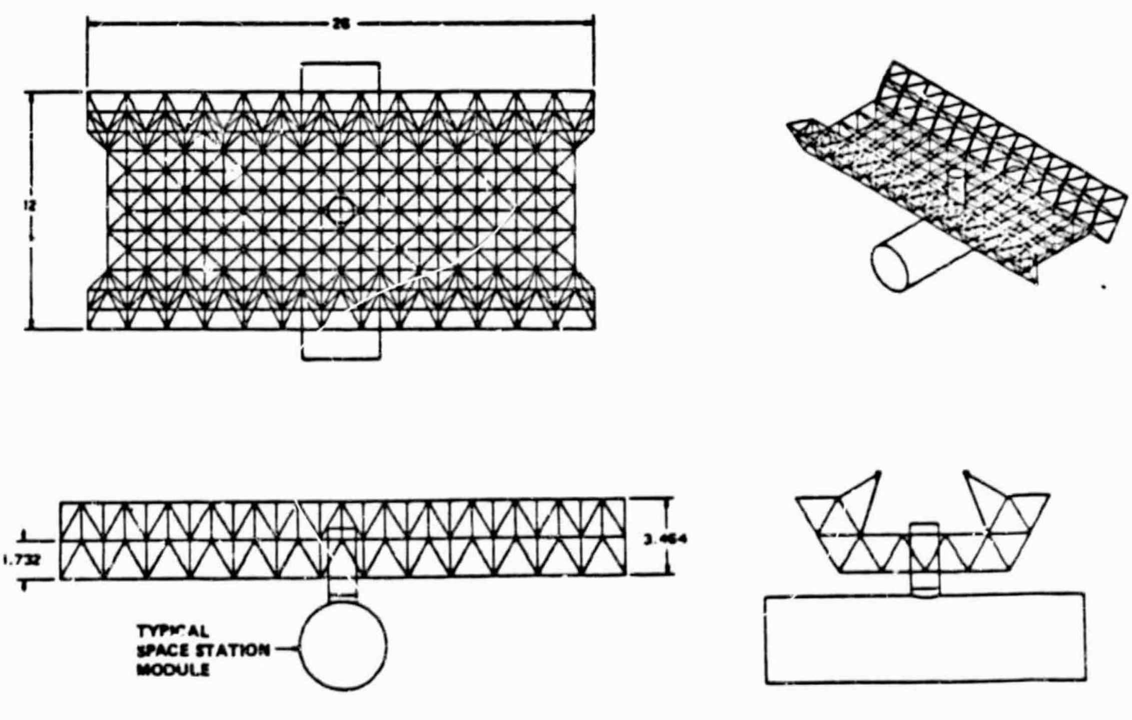

Figure 3.1.2-1. TDM Configuration LSS-1, Construction and Storage Facility

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auxiliary lights, etc. Segments of the platform could have floor panels installed to provide storage areas for small modules.

The packaging and deployment scheme for the construction/storage facility is shown in Figure 3.1.2-2. The 5.08cm diameter surface members of the pentahedral truss are hinged in the center and fold inward (upper left figure). The complete truss folds into a package 1.1m x 2.4m x 2.4m with the struts arranged as shown in the end view in the right-hand figure.

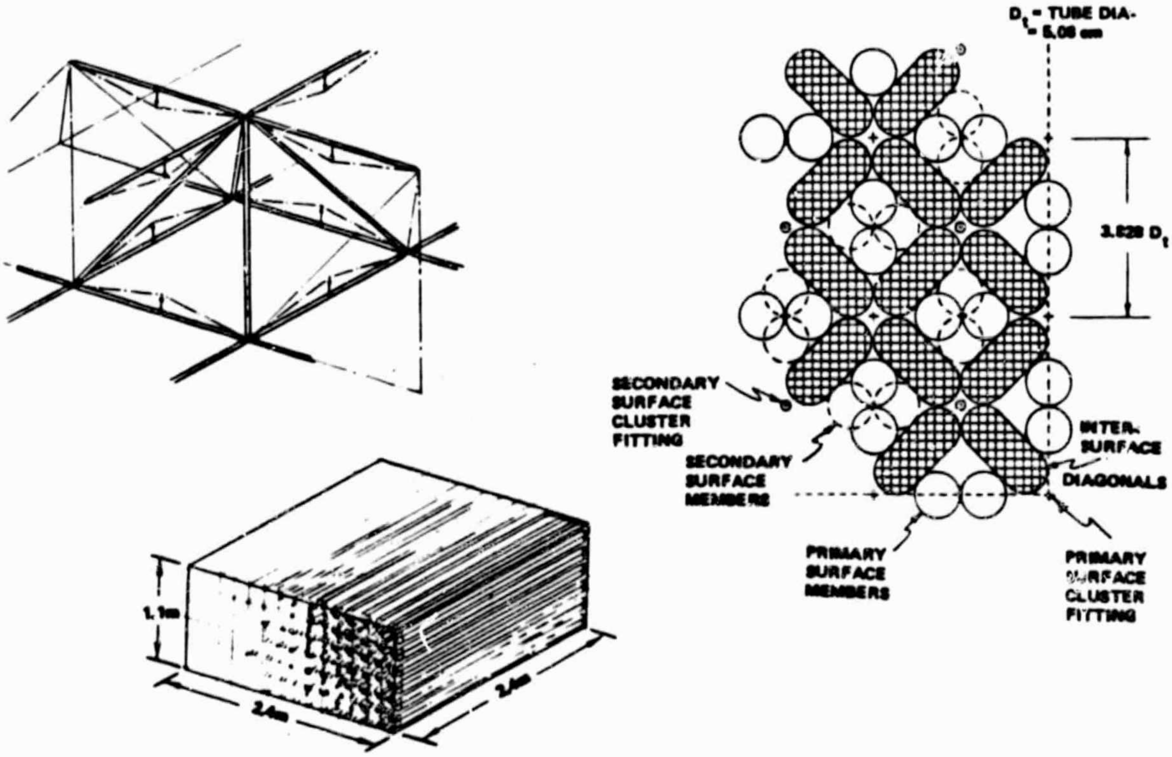

Figure 3.1.2-2. Construction and Storage Facility Packaging

The benefits derived from TDM LSS-1 are summarized in Table 3.1.2-1.

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Table 3.1.2-1. LSS-1 Mission Benefits

- **DEPLOYMENT AND ASSEMBLY DEMONSTRATION**
- **SUBSYSTEM INSTALLATION AND CHECKOUT**
- **DEMONSTRATE MAN'S ROLE AND CAPABILITIES IN SPACE**
- **PROVIDES PERMANENT SPACE STATION FACILITY**
    - **STORAGE FOR TOOLS, ASSEMBLIES, ORBITER PAYLOADS, ETC.**
    - **CONSTRUCTION FACILITY FOR OTHER SPACE SYSTEMS**
    - **FACILITY FOR SATELLITE SERVICING**

TDM Configuration LSS-2: Servicing Hangar

This TDM configuration is a lightweight protective hangar to be added to the construction and storage facility (LSS-1) as shown in figure 3.1.2-3. It is designed to protect EVA astronauts while performing such tasks as OTV servicing and small satellite refurbishment. It would protect the OTV, satellite and crew from solar radiation, would

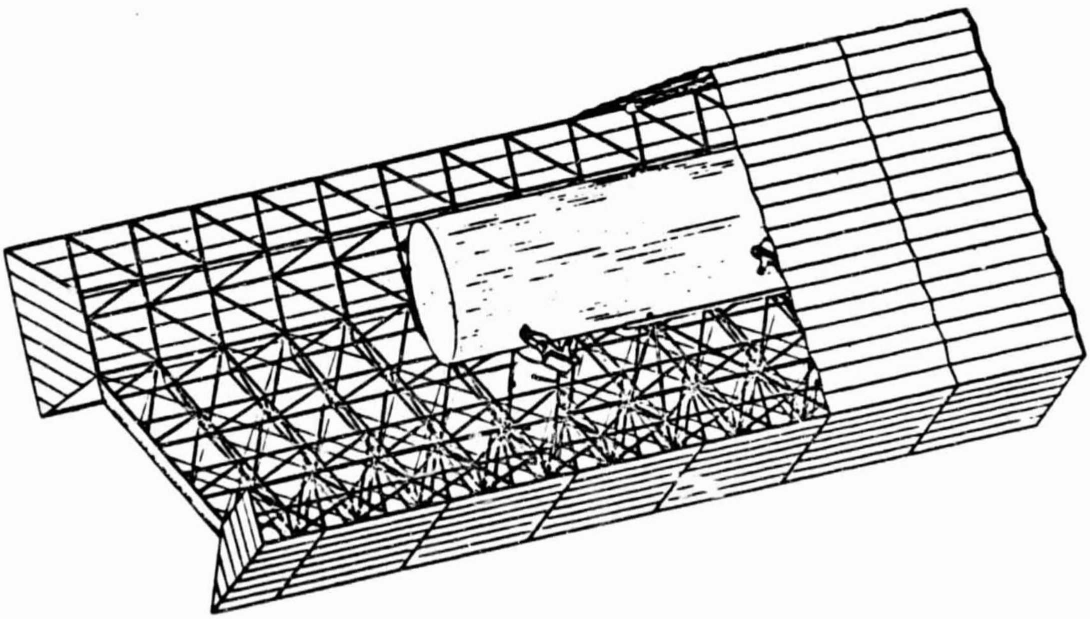

Figure 3.1.2-3. TDM Configuration LSS-2, Servicing Hangar

provide containment in the event a small object floated free, and would allow untethered freedom for the crew when fully enclosed. Some of the panels would be permanently attached to the platform while the "roof" is retractable using extendable masts. The "ridge" structure would contain lights for illumination during EVA activity. The figure shows a representation of a large payload attached to the payload support rails.

The benefits of this TDM to LSS Technology are shown in Table 3.1.2-2.

Table 3.1.2-2. LSS-2 Mission Benefits

- DEPLOYMENT AND ASSEMBLY DEMONSTRATION
- SUBSYSTEM INSTALLATION AND CHECKOUT
- DEMONSTRATE MAN'S ROLE AND CAPABILITIES IN SPACE
- PROVIDES PERMANENT SPACE STATION FACILITY
  - HANGAR FOR OTV SERVICING
  - PROTECTED FACILITY FOR SMALL SATELLITE SERVICING

TDM Configuration LSS-3: Passive Microwave Radiometer

A large antenna system can be used to demonstrate a variety of mission objectives. The antenna system may serve as a test bed used to evaluate membrane surface installation techniques and various reflector shape control systems. It can also provide maximum benefit by being a functional antenna system upon completion of the technology demonstration. Construction of the antenna system will require both deployable structures and space assembled structures and subsystems.

Several antenna systems were considered for use as a TDM: a large communications antenna, a very long baseline interferometer (VLBI), and a microwave radiometer system (MRS). The communications antenna was eliminated because of the low earth orbit of the

Space Station. The large communications antenna such as the land mobile satellite systems (LMSS) are designed for operation in geosynchronous orbit. Therefore the functional demonstration of a communication antenna while attached to the Space Station presents problems. The VLBI can be used in low earth orbit, but VLBI technology doesn't necessarily require a very large antenna.

The other antenna design which can meet the mission objectives is a version of a microwave radiometer spacecraft (MRS); which has been proposed [46] to provide earth resource measurements such as soil moisture sensing and global crop forecasting. The microwave radiometer antenna was selected as a TDM for several reasons: (1) an MRS of large, but reasonable, size (100 m diameter) can be functionally operated in LEO, (2) it doesn't require a gimballed pointing system since both the space station and the MRS are earth oriented, and (3) following its use as a TDM, it can be placed in a higher orbit (600-700 km) to continue its use as a scientific instrument.

Microwave soil moisture sensing requires a large antenna system in order to provide the necessary spatial resolution. The soil properties information is radiated from the Earth's surface as brightness temperature. This microwave radiation information is reflected via the large diameter dish to the receiving horn of a radiometer at the focus of the reflector. A microwave dish 100 meters in diameter will provide good resolution from low Earth orbit.

The basic configuration of the microwave radiometer spacecraft is shown in Figure 3.1.2-4. The reflector is a spherical segment, 100m (328 ft) in diameter, with a spherical radius of 158.6m (520 ft). The reflector has severe requirements on maintaining this shape. Deviation from the theoretical spherical radius is limited to 6mm or less. A reflective mesh material will make up the reflector surface because of its low mass and efficient packaging potential. An active control system is required for fine shape control because of the flexibility of the mesh and the surface accuracy requirements. A 104

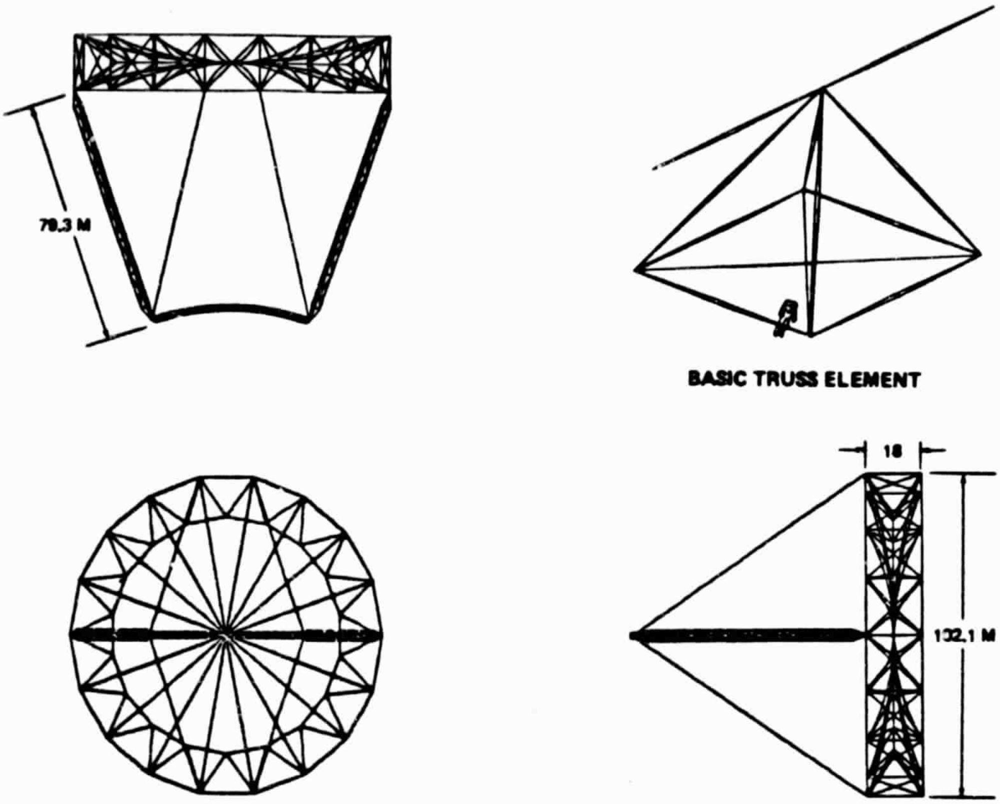

Figure 3.1.2-4. TDM Configuration LSS-3, Passive Microwave Radiometer

meter diameter toroidal ring provides structural support to the reflector surface control cables as well as continuity between the dish surface and the support columns. The ring will also provide mounting support at nodal attachment points for subsystem modules and Space Station interface structure. The support ring is of pentahedral truss construction, utilizing 18 meter tapered columns as the structural elements. Each strut is assembled from two 9 meter nestable halves. The strut halves package dixie cup fashion to achieve high packaging density. Crossed cables in tension across the square face of each pentahedron provide structural stability.

An initial array of 10 radiometers and feed horns (more may be added later at other frequencies) is mounted along a 50 meter long curved beam at a focal arc of the reflector. The beam curvature is a spherical radius of 79.3 meters, (one-half the spherical radius of the reflector) so that each horn is pointed at a prescribed target on the reflector. The

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radiometer support truss is a deployable box beam with truss bays 2 meters by 2 meters in cross section. The feed horns are designed to be split along their longitudinal centerlines for more efficient packaging, with assembly accomplished on orbit.

The feed array structure is supported by tensioned stiffened columns and stabilized by cables to the ring truss. The 79.3 meter feed support struts are foldable (7 segments), tension stiffened masts. The central tubular member carries the tension and compression loads while the outrigger system of three cables provide bending stiffness. The mast can be folded after relaxing the cable tension and folding the cable supports against the central tube.

The entire spacecraft (without the control system/power/data handling module) has a mass of 7500 kilograms. Addition of the control system/power/data handling module will permit free flying operations independent of the Space Station for eventual system deployment.

Table 3.1.2-3 summarizes the benefits which can be derived from TDM LSS-3.

Table 3.1.2-3. LSS-3 Mission Benefits

- **DEPLOYMENT AND ASSEMBLY DEMONSTRATION**
- **SUBSYSTEM INSTALLATION AND CHECKOUT**
- **DEMONSTRATE MAN'S ROLE AND CAPABILITIES IN SPACE**
- **DEPLOYMENT OR INSTALLATION OF MEMBRANE SURFACE**
- **PRECISION CONTROL OF LSS**
- **FUTURE TECHNOLOGY TESTBED**
  - **CONTROL SYSTEMS**
  - **SURFACE MANAGEMENT AND CONTROL**
  - **DAMPING AUGMENTATION**

TDM Configuration LSS-4: Precision Optical System

A large precision optical system can be used to demonstrate several mission objectives. The optical system requires a high-stiffness, accurately shaped truss structure to support the mirror surface. The mirror surface itself is made up of mirror segments which are individually controlled to obtain the necessary accuracy. Precise control of the secondary mirror surface and support structure will also be necessary. A large precision optical system will require significant in-space assembly.

One spacecraft design which can fulfill the described mission objectives is a large-aperture infrared system. This spacecraft requires very high accuracy to accomplish the infrared astronomy mission objectives. Additionally the mirror surfaces will have to be kept at cold (150°K) temperatures with little variation.

The overall configuration of the precision optical system is shown in Figure 3.1.2-5 with part of the multi-layer insulation light shield removed to show interior details. This is a

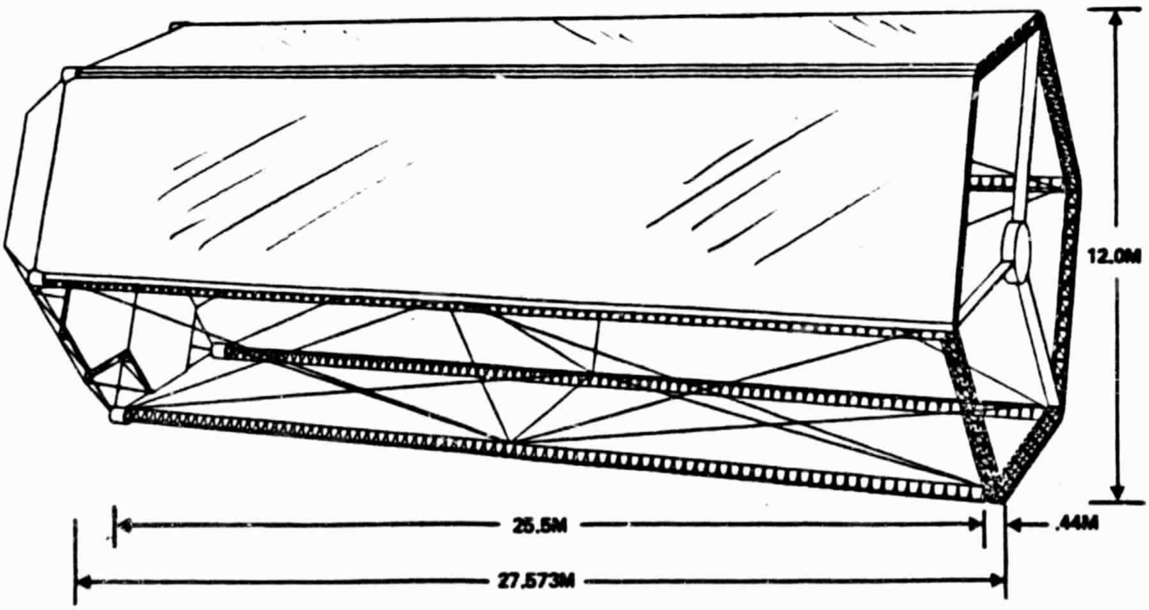

Figure 3.1.2-5. TDM Configuration LSS-4, Precision Optical System

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Cassegrainian mirror design which will permit a sufficiently wide optical field of view. The Cassegrainian system has a large primary mirror which directs the infrared information to the smaller secondary mirror which, in turn, focuses back through a small hole in the primary onto the instrument package. The primary surface is made up of seven hexagonal mirrors (2 meters on a side) which are sized to fit inside the shuttle payload bay envelope. The secondary surface is a single mirror 2.5 meters in diameter and 25.5 meters from the primary surface. Initial studies indicate that the mirror surfaces may be kept at the required temperature using passive techniques which include multi-layer insulation and infrared radiation baffles.

The primary mirror truss structure is shown in top and side views in Figure 3.1.2-6. Each truss element is assembled from two 1 meter nestable halves. This mirror support

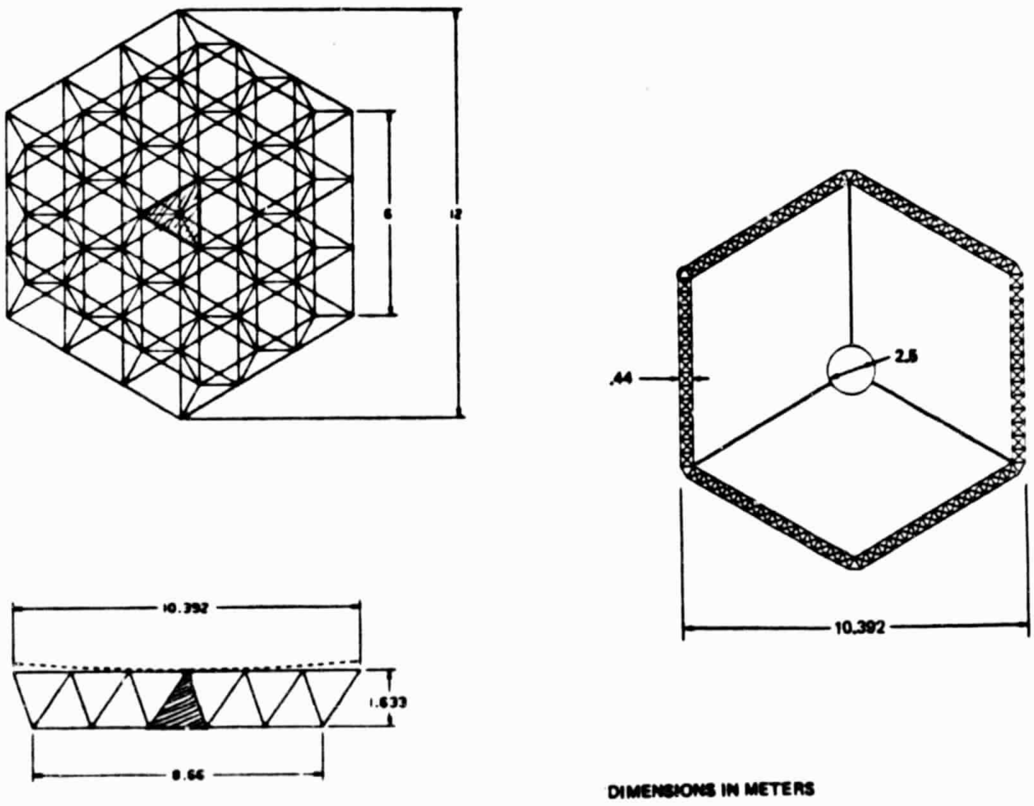

Figure 3.1.2-6. Precision Optical System Details

structure is assembled around the instrument housing (shown with cross-hatching). The structure must be highly rigid to accurately support the segmented mirror and actuators. Each mirror segment is actively controlled by three actuators mounted on the support truss. The adaptive optics system must control the accuracy of each mirror segment to less than 5 micrometers.

The secondary mirror, its tri-beam support, and the mirror support ring are also shown in Figure 3.1.2-6. The support ring is assembled from six deployable box beam trusses with truss bays .44 meters square in cross section. The tri-beam supports are stiffened composite panels. This secondary mirror system is deployed out from the primary structure by six extendable masts which are stabilized by compression struts and tensioned cables. Multi-layer insulation and baffels are added to obtain an operational system.

The operational spacecraft with a sample instrumentation load has a mass of 5100 kilograms. The spacecraft may be operated independently of the Space Station with the addition of a control system/power/data handling module. The benefits of this mission to LSS technology advancement are shown in Table 3.1.2-4.

Table 3.1.2-4. LSS-4 Mission Benefits

- DEPLOYMENT AND ASSEMBLY DEMONSTRATION
- ASSEMBLY OF RIGID, HIGH-PRECISION STRUCTURE
- SUBSYSTEM INSTALLATION AND CHECKOUT
- PRECISION CONTROL OF LSS
- ADAPTIVE OPTICS; CONTROL OF MULTI-MIRROR SURFACE
- DEMONSTRATE MAN'S ROLE AND CAPABILITIES IN SPACE
- FUTURE TECHNOLOGY TESTBED
  - CONTROL SYSTEMS (POINTING AND OPTICAL)
  - DAMPING AUGMENTATION
  - THERMAL CONTROL

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Figure 3.1.2-7 shows one method of packaging the optical system in the shuttle payload bay. The hexagonal primary mirrors are sized to fit inside the 4.4 meter diameter payload bay envelope. The total packaged length is approximately 5 meters.

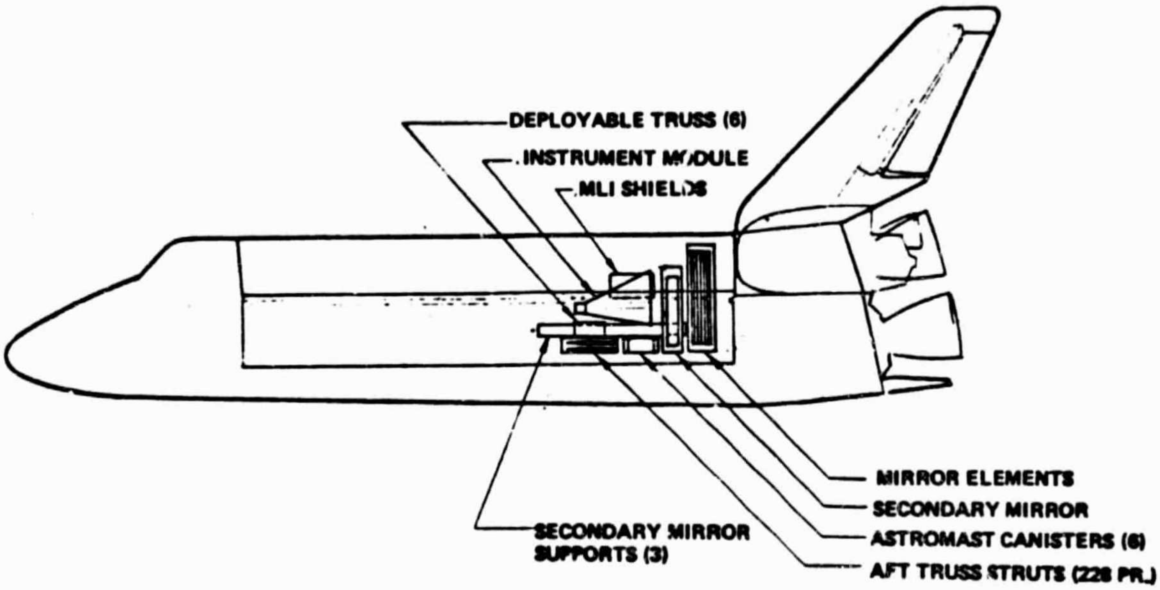

Figure 3.1.2-7. Precision Optical System Packaging

3.2 Mission Operations Analysis

This section summarizes an analysis of the requirements for constructing the four technology development missions on a Space Station.

The preliminary TDM design data and drawings were used to drive out the construction requirements of each technology development mission. This information was used to identify support equipment concepts, man-machine tradeoffs, and to define a tentative crew size, and work schedule. TDM concepts and operational procedures were refined by making third level functional flow diagrams for each mission to expose any problem areas. These diagrams were updated as trades were completed and better definition of equipment, interfaces, man-machine function, and skills required for each mission was made.

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3.2.1 Functional Flow Diagrams

Utilizing the preliminary design information, drawings, and mission data forms, a preliminary set of reference construction tasks were identified for each mission. These construction sequences were then upgraded to third level functional flow diagrams to define end to end construction and test operations for each mission. This data results in an organized presentation of the mission construction and test sequences to be carried out. The functional flow diagrams were refined as the man-machine function analysis, timelines, and crew requirements were identified and analyzed. The final functional flow diagrams are presented in Figures 3.2.1-1 through 3.2.1-4. The construction sequences for each of the four TDMs are shown graphically in Figures 3.2.1-5 through 3.2.1-8.

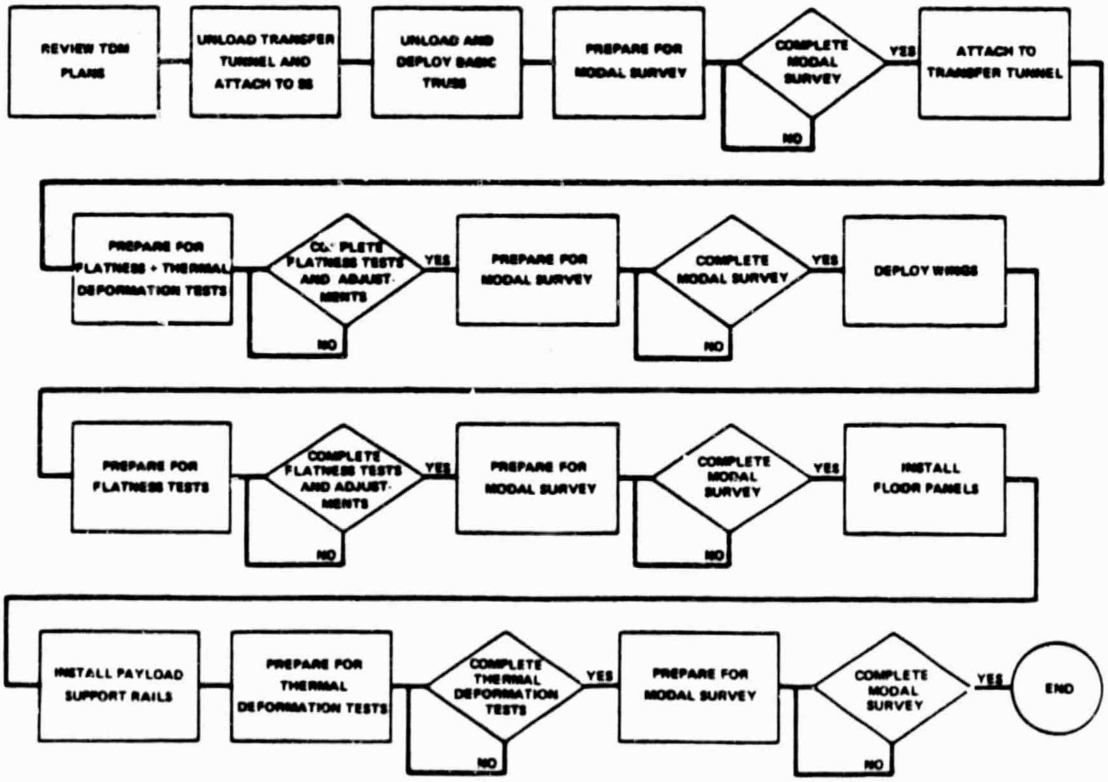

Figure 3.2.1-1. Construction and Storage Facility (LSS-1) Functional Flow

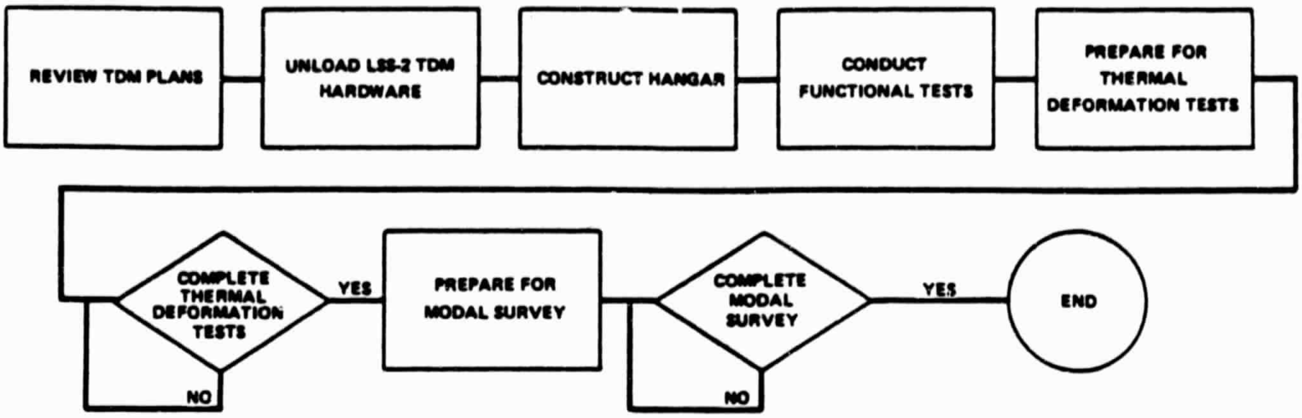

Figure 3.2.1-2. Servicing Hangar (LSS-2) Functional Flow

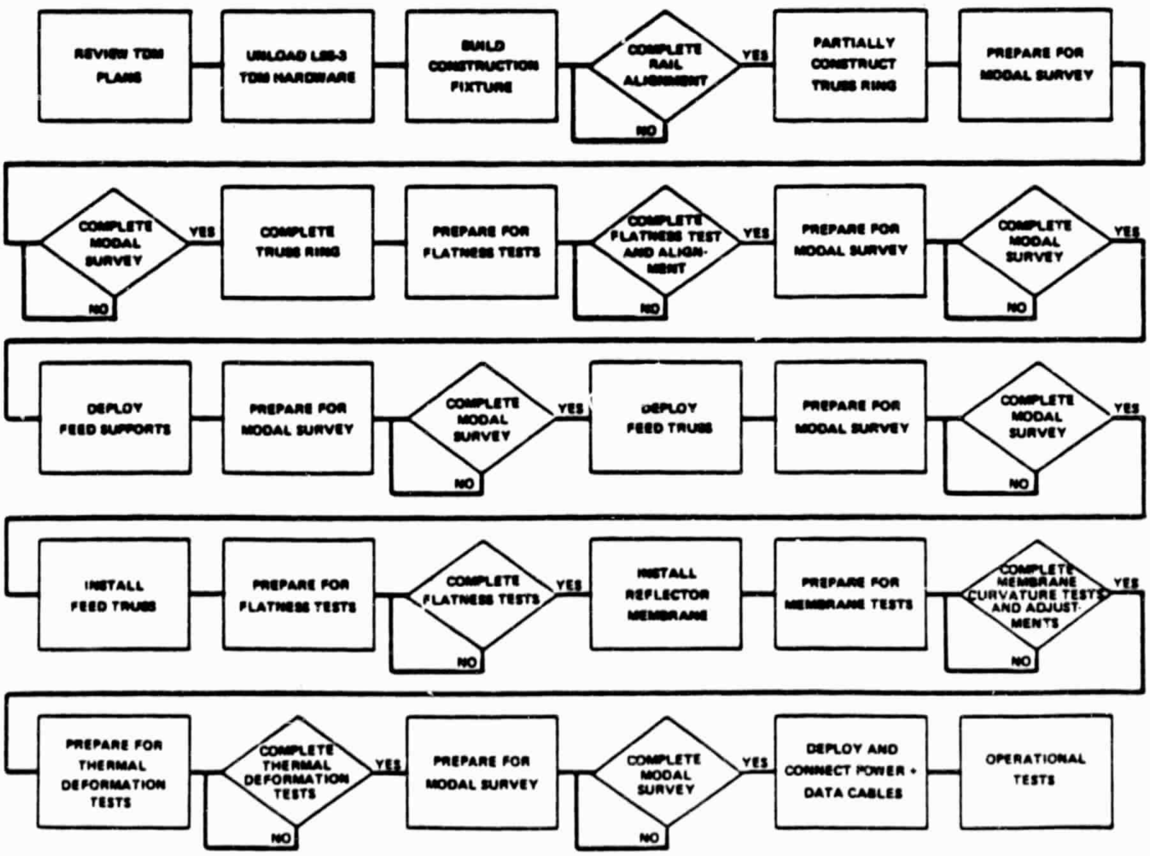

Figure 3.2.1-3. Microwave Radiometer (LSS-3) Functional Flow

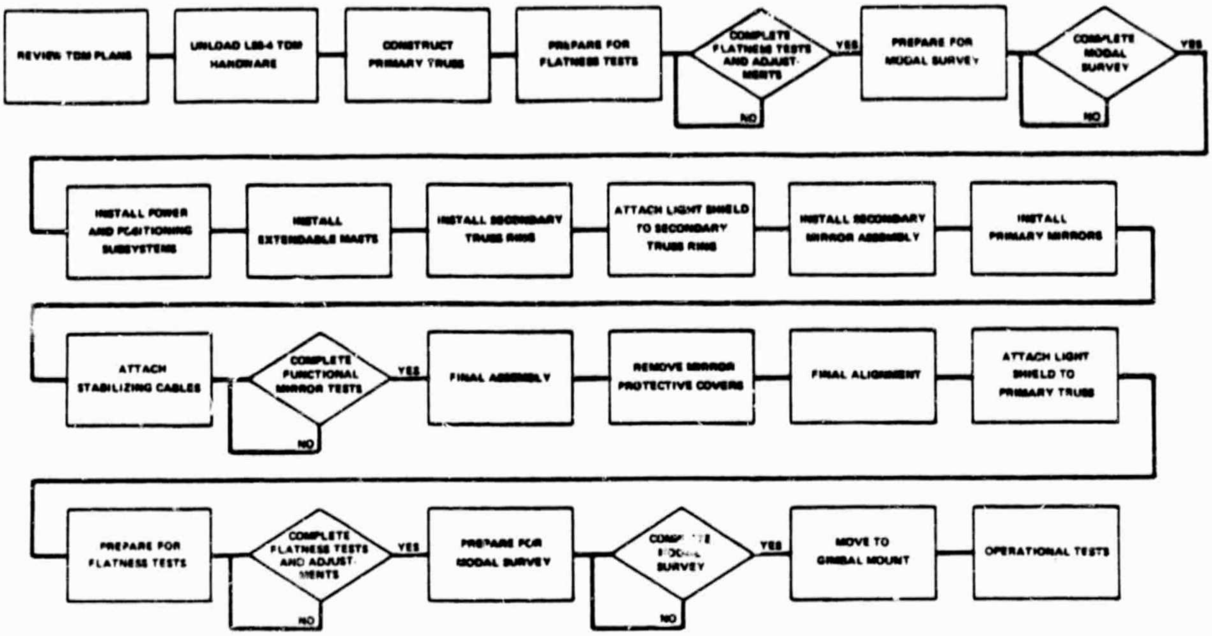

Figure 3.2.1-4. Precision Optical System (LSS-4) Functional Flow

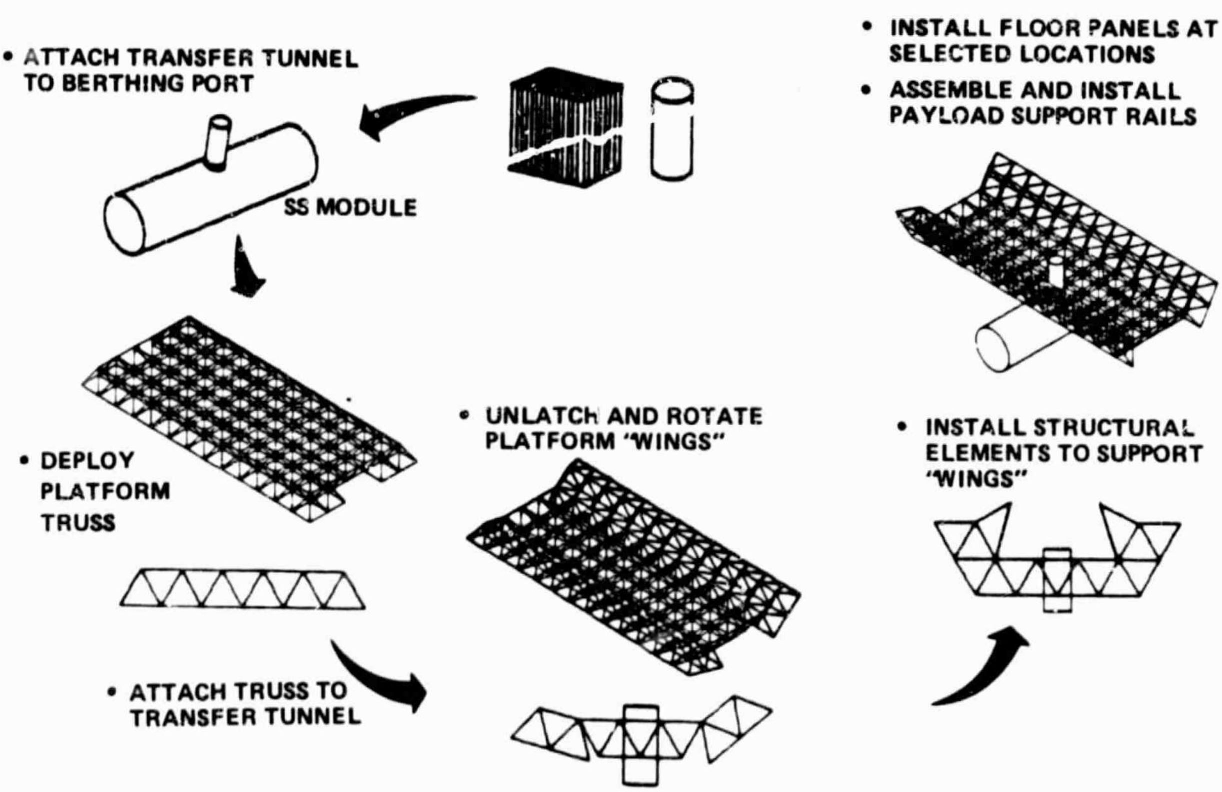

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Figure 3.2.1-5. LSS-1 Construction Sequence

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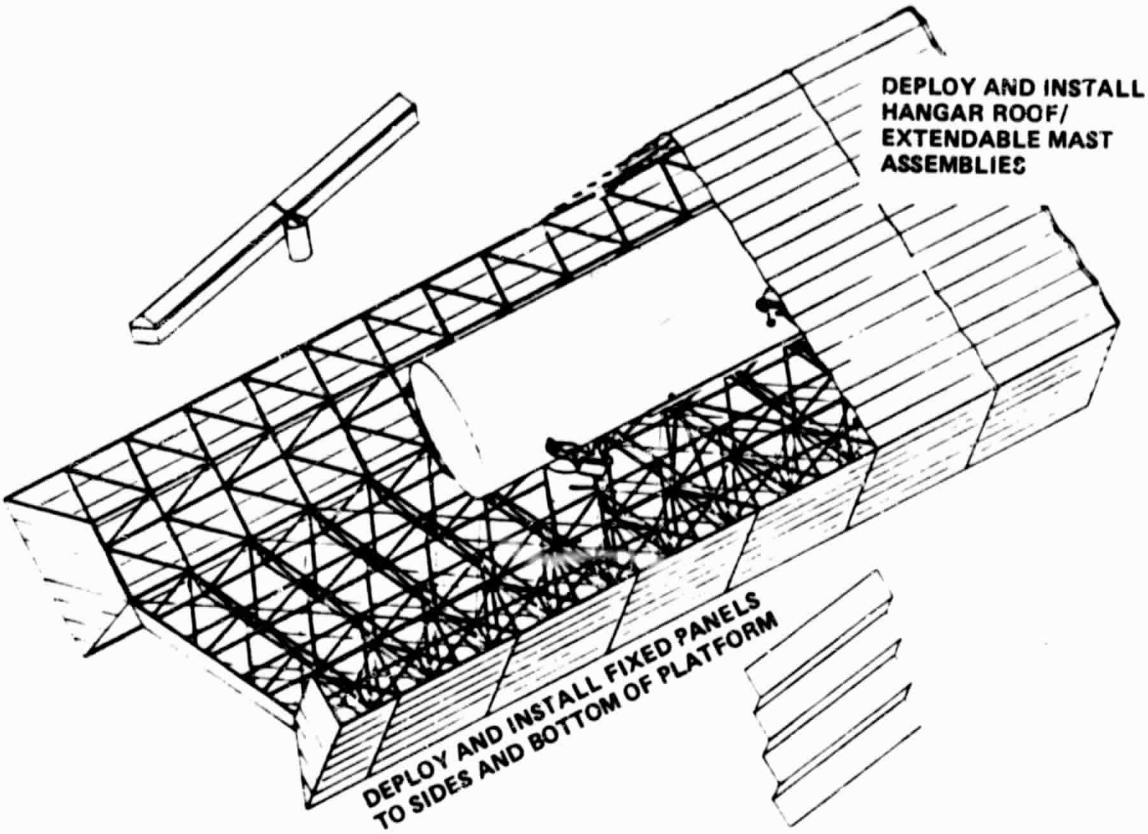

Figure 3.2.1-6. LSS-2 Construction Sequence

3.2.2 Man-Machine Function Allocation

In order to make the man-machine function allocations, the functional flow diagrams were analyzed to identify the major components of the system and the general operating requirements. Each functional step was reviewed to determine if it should be performed manually, by an operator with the aid of a machine, or whether it should be totally automatic. Table 3.2.2-1 provide the results of this analysis.

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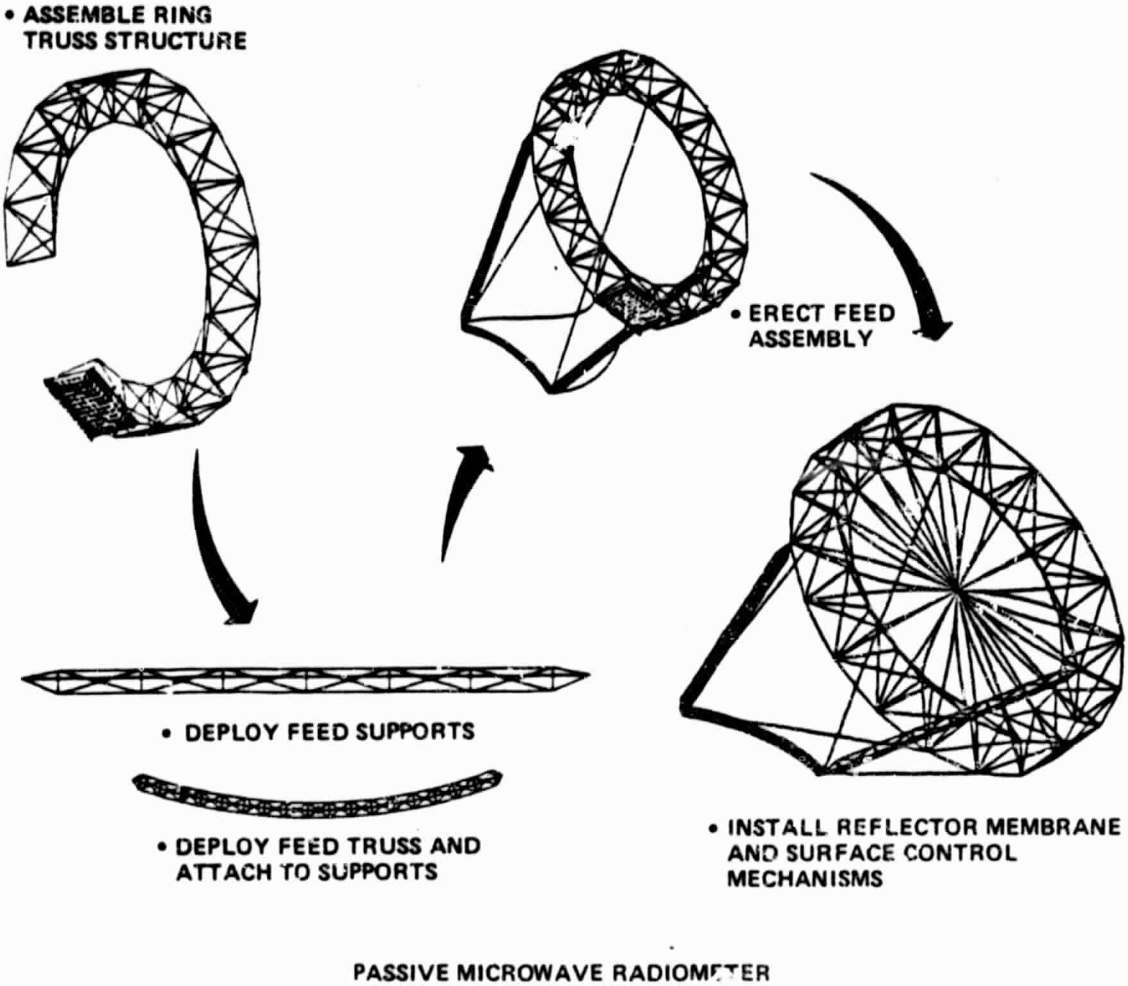

Figure 3.2.1-7. LSS-3 Construction Sequence

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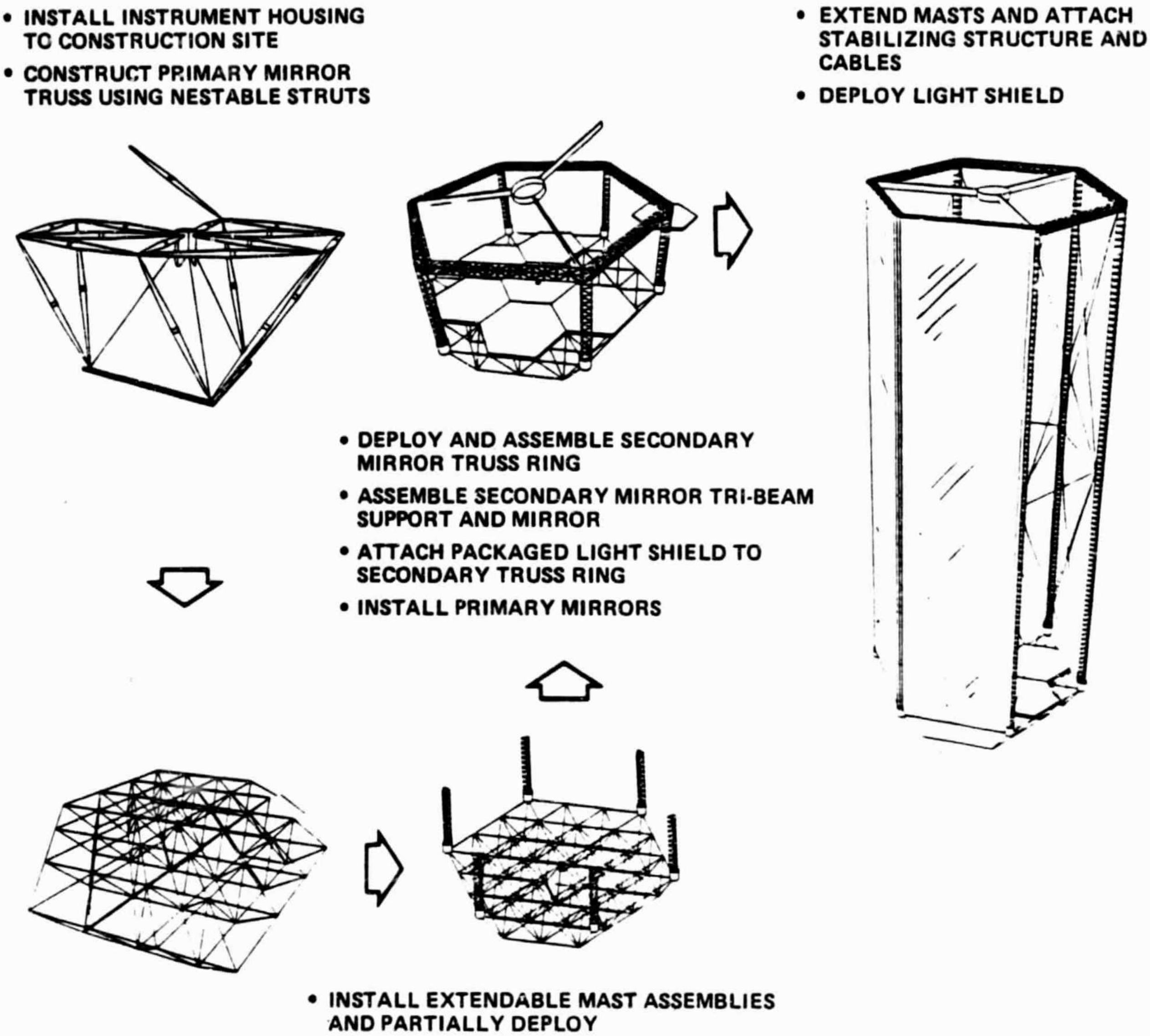


LARGE OPTICAL SYSTEM

Figure 3.2.1-8. LSS-4 Construction Sequence

Table 3.2.2-1. Man/Machine Allocations

CONSTRUCTION/STORAGE FACILITY

FUNCTION		FUNCTION BEST PERFORMED BY		
		MAN ONLY	MACHINE ONLY	MAN AND MACHINE
1.1	REVIEW ASSEMBLY PROCEDURES	X		X
1.2	UNLOAD TRANSFER TUNNEL AND ATTACH TO SPACE STATION			X
1.3	UNLOAD AND DEPLOY BASIC TRUSS STRUCTURE			X
1.4	CONDUCT MODAL SURVEY			X
1.5	ATTACH TRUSS TO TRANSFER TUNNEL			X
1.6	CONDUCT FLATNESS AND THERMAL DEFLECTION TESTS			X
1.7	DEPLOY WINGS	X		
1.8	INSTALL FLOOR PANELS			X
1.9	INSTALL PAYLOAD SUPPORTS	X		

Table 3.2.2-1. Man/Machine Allocations (Continued)

SERVICING HANGAR

FUNCTION		FUNCTION BEST PERFORMED BY		
		MAN ONLY	MACHINE ONLY	MAN AND MACHINE
2.1	REVIEW ASSEMBLY PROCEDURES	X		
2.2	TRANSFER CONTAINERS TO CONSTRUCTION/ STORAGE AREA			X
2.3	CONSTRUCT HANGAR			X
2.4	CONDUCT FUNCTIONAL TESTS			X
2.5	CONDUCT THERMAL DEFLECTION TESTS			X
2.6	CONDUCT MODAL SURVEY			X

Table 3.2.2-1. Man/Machine Allocations (Continued)

MICROWAVE RADIOMETER

FUNCTION		FUNCTION BEST PERFORMED BY		
		MAN ONLY	MACHINE ONLY	MAN AND MACHINE
3.1	REVIEW ASSEMBLY PROCEDURES	X		
3.2	TRANSFER CONTAINERS TO CONSTRUCTION/ STORAGE AREA			X
3.3	BUILD CONSTRUCTION FIXTURE			X
3.4	COMPLETE RAIL ALIGNMENT			X
3.5	ASSEMBLE TRUSS RING			X
3.6	CONDUCT MODAL SURVEY			X
3.7	CONDUCT FLATNESS TESTS AND ADJUSTMENTS			X
3.8	DEPLOY FEED SUPPORTS	X		
3.9	DEPLOY FEED TRUSS	X		
3.10	INSTALL FEED TRUSS	X		
3.11	INSTALL REFLECTOR MEMBRANE			X
3.12	CONDUCT MEMBRANE CURVATURE TESTS AND ADJUSTMENTS			X
3.13	DEPLOY AND CONNECT POWER AND DATA CABLES	X		

Table 3.2.2-1. Man/Machine Allocations (Continued)

PRECISION OPTICAL SYSTEM

FUNCTION		FUNCTION BEST PERFORMED BY		
		MAN ONLY	MACHINE ONLY	MAN AND MACHINE
4.1	REVIEW ASSEMBLY PROCEDURES	X		
4.2	TRANSFER CONTAINERS TO CONSTRUCTION/ STORAGE AREA			X
4.3	INSTALL HOLDDOWN FIXTURE	X		
4.4	CONSTRUCT TRUSS			X
4.5	CONDUCT FLATNESS AND THERMAL DEFLECTION TESTS			X
4.6	CONDUCT MODAL SURVEY			X
4.7	INSTALL POWER AND POSITIONING SUBSYSTEMS			X
4.8	INSTALL EXTENDABLE MASTS	X		
4.9	INSTALL SECONDARY TRUSS RING	X		
4.10	ATTACH LIGHT SHIELD TO SECONDARY RING			X
4.11	INSTALL SECONDARY MIRROR ASSEMBLY			X
4.12	INSTALL PRIMARY MIRRORS			X
4.13	ATTACH STABILIZING CABLES	X		
4.14	COMPLETE MIRROR FUNCTIONAL TEST			X
4.15	FINAL ASSEMBLY	X		
4.16	REMOVE MIRROR PROTECTIVE COVERS	X		
4.17	FINAL ALIGNMENT			X
4.18	ATTACH LIGHT SHIELD TO PRIMARY TRUSS	X		
4.19	MOVE TO GIMBAL MOUNT			X
4.20	TEST OPERATION AND FINAL ALIGNMENT			X

3.2.3 LSS Technology Development Mission Timelines

Preliminary timelines were prepared utilizing the construction sequence, the man-machine function allocation, crew skills identified and Space Station interfaces as noted in this study. These timelines are to "test" on paper the practicality and feasibility of our design concepts. Problem areas revealed by this process were reviewed and resolved with our design engineers. The timelines were then updated to reflect any changes.

The times used for generating timelines for the LSS TDM's construction and test tasks were taken from our data base of operations task time data accumulated during our space station studies. The strut assembly task times were taken from Large Space Systems Technology—1981 [3].

The times presented in Table 3.2.3-1 are an itemization of times allocated to each function in the functional flow diagrams. Operators are assumed to be fresh at the start of each work shift. It is further assumed that all operators are trained on the ground and in a natural buoyancy facility prior to the mission. These task times include time spent in transitions to work sites, setting up of tethers and work restraints, adjusting the sun visor, rest breaks and meals.

The total LSS TDM construction times are summarized in Table 3.2.3-2. Because the timeline assumed a smooth flow of work without interruptions or problems, a 25% contingency time has been added to the total time. The total has also been shown in shifts so that if sufficient crew members are available the length of construction in days could be shortened by working two or even three shifts.

Table 3.2.3-1. TDM Construction Timelines

LSS-1 STORAGE/CONSTRUCTION PLATFORM

		TIME IN MINUTES
1.	REVIEW ASSEMBLY PROCEDURES	480
2.	TRANSFER STORAGE/CONSTRUCTION PLATFORM CONTAINERS TO SPACE STATION CONSTRUCTION STORAGE AREA	146
3.	DEPLOY PLATFORM	124.6
4.	CONDUCT MODAL SURVEY	290
5.	ATTACH TO TRANSFER TUNNEL	122.88
6.	CONDUCT FLATNESS AND THERMAL DEFORMATION TESTS	290
7.	CONDUCT MODAL SURVEY	290
8.	DEPLOY WINGS	184
9.	CONDUCT FLATNESS AND THERMAL DEFORMATION TESTS	290
10.	CONDUCT MODAL SURVEY	290
11.	INSTALL FLOOR PANELS	162
12.	INSTALL PAYLOAD SUPPORTS	126.04
13.	CONDUCT FLATNESS AND THERMAL DEFORMATION TESTS	290
14.	CONDUCT MODAL SURVEY	290
		3,375.52

Table 3.2.3-1. TDM Construction Timelines (Continued)

LSS-2 SERVICING HANGAR

		TIME IN MINUTES
1.	REVIEW ASSEMBLY PROCEDURES	240
2.	TRANSFER HANGAR CONTAINERS TO SPACE STATION CONSTRUCTION STORAGE AREA	60
3.	CONSTRUCTION HANGAR	191.63
4.	CONDUCT FUNCTIONAL TESTS	180
5.	CONDUCT THERMAL DEFORMATION TESTS	290
6.	CONDUCT MODAL SURVEY	290
		1,251.63

Table 3.2.3-1. TDM Construction Timelines (Continued)

LSS-3 MICROWAVE RADIOMETER

		TIME IN MINUTES
1.	REVIEW ASSEMBLY PROCEDURES	480
2.	TRANSFER MICROWAVE RADIOMETER CONTAINERS TO SPACE STATION CONSTRUCTION STORAGE AREA	146
3.	BUILD CONSTRUCTION FIXTURE	274.6
4.	COMPLETE RAIL ALIGNMENT	193
5.	CONSTRUCT PARTIAL TRUSS RING	23[illegible].4
6.	CONDUCT MODAL SURVEY	290
7.	COMPLETE TRUSS RING	251
8.	CONDUCT FLATNESS TESTS AND ADJUSTMENTS	290
9.	CONDUCT MODAL SURVEY	290
10.	DEPLOY FEED SUPPORTS	146.54
11.	CONDUCT MODAL SURVEY (FEED SUPPORT)	290
12.	DEPLOY FEED TRUSS	136
13.	CONDUCT MODAL SURVEY (FEED TRUSS)	290
14.	INSTALL FEED TRUSS	166
15.	CONDUCT FLATNESS TEST	290
16.	INSTALL REFLECTOR MEMBRANE	212
17.	CONDUCT MEMBRANE CURVATURE TESTS AND ADJUSTMENTS	290
18.	CONDUCT THERMAL DEFORMATION TESTS	290
19.	CONDUCT MODAL SURVEY	290
20.	DEPLOY AND CONNECT POWER AND DATA CABLES	98
21.	TEST OPERATION AND FINAL ALIGNMENT	2,000
		6,944.54

Table 3.2.3-1. TDM Construction Timelines (Continued)

LSS-4 PRECISION OPTICAL

		TIME IN MINUTES
1.	REVIEW ASSEMBLY PROCEDURES	480
2.	TRANSFER PRECISION OPTICAL CONTAINERS TO SPACE STATION CONSTRUCTION STORAGE AREA	146
3.	INSTALL HOLD DOWN FIXTURE	152
4.	TRUSS CONSTRUCTION	542
5.	CONDUCT FLATNESS AND THERMAL DEFORMATION TESTS	[illegible]
6.	CONDUCT MODAL SURVEY	240
7.	INSTALL POWER AND POSITIONING SUBSYSTEMS	135
8.	INSTALL EXTENDABLE MASTS	188
9.	INSTALL SECONDARY TRUSS RING	176
10.	ATTACH LIGHT SHIELD TO SECONDARY RING	129
11.	INSTALL SECONDARY MIRROR ASSEMBLY	186
12.	INSTALL PRIMARY MIRRORS	268
13.	ATTACH STABILIZING CABLES	258.8
14.	COMPLETE FUNCTIONAL MIRROR TEST	325
15.	FINAL ASSEMBLY	245
16.	REMOVE MIRROR PROTECTIVE COVERS	158
17.	FINAL ALIGNMENT	168
18.	ATTACH LIGHT SHIELD TO PRIMARY TRUSS	175
19.	CONDUCT FLATNESS TEST	290
20.	CONDUCT MODAL SURVEY	250
21.	MOVE TO GIMBAL MOUNT	74
22.	TEST OPERATION AND FINAL ALIGNMENT	4,800
		9,724.8

Table 3.2.3-2. LSS TDM Construction Times

MISSION	MINUTES	CONSTRUCTION TIME *			SHIFTS
		HOURS	25% CONTINGENCY	TOTAL HOURS	
LSS-1	3,375.52	56.26	14.06	70.32	8.79
LSS-2	1,251.63	20.86	5.22	26.08	3.26
LSS-3	6,944.54	115.74	28.94	144.68	18.08
LSS-4	9,724.80	162.08	40.52	202.60	25.33

* CONSTRUCTION ON A SPACE STATION

3.2.4 Define Crew Requirements

The man allocated functions and the timeline data developed in Sections 3.2.2 and 3.2.3 were integrated with the crew skills defined in our Space Station study. The Space Station studies identified 15 crew skills which are presented in Table 3.2.4-1, along with the skill level identification. It was determined that seven of these skills were required for the LSS TDM construction and test tasks. These seven skills are shown in Table 3.2.4-2. The same skill levels that were identified in the Space Station study apply to the LSS TDM tasks.

Table 3.2.4-1. Skills Group

1. NO SPECIAL SKILL REQUIRED
2. MEDICAL/BIOLOGICAL RESEARCH
3. PHYSICAL SCIENCES RESEARCH
4. EARTH AND OCEAN SCIENCES RESEARCH
5. ENGINEERING
6. ASTRONOMY RESEARCH
7. SPACECRAFT SYSTEMS OPERATIONS – DATA
8. SPACECRAFT SYSTEMS OPERATIONS – ELECTRONICS
9. SPACECRAFT SYSTEMS OPERATIONS – MECHANISMS
10. SPACECRAFT SYSTEMS OPERATIONS – FLUIDS
11. SPACE STATION SUBSYSTEMS OPERATION AND MAINTENANCE
12. EVA CHERRYPICKER OPERATIONS
13. EVA WORKSTATION OPERATIONS
14. MOTV PILOTING
15. TELEOPERATOR PILOTING

SKILL LEVELS

1. TASK TRAINABLE
2. TECHNICAL
3. PROFESSIONAL

Table 3.2.4-3 describes the crew jobs required to perform the LSS TD missions. There is not a one-to-one relationship between the crew jobs and the number of crew members.

Table 3.2.4-2. LSS TDM Skill Group

1. ENGINEERING
2. SPACECRAFT SYSTEMS OPERATIONS – DATA
3. SPACECRAFT SYSTEMS OPERATIONS – ELECTRONICS
4. SPACECRAFT SYSTEMS OPERATIONS – MECHANISMS
5. SPACE STATION SUBSYSTEMS OPERATION AND MAINTENANCE
6. EVA CHERRYPICKER OPERATIONS
7. EVA WORKSTATION OPERATIONS

Table 3.2.4-3. Crew Skill Descriptions

JOB TITLE	WORK LOCATION
ENGINEERING	IVA SPACE STATION LOCATIONS

BASIC TASKS

PRIMARY FUNCTION IS TO SUPERVISE CONSTRUCTION, AND TEST OF LSS TECHNOLOGY DEVELOPMENT MISSIONS

SECONDARY FUNCTION IS TO PROVIDE MANAGEMENT CONTROL OF MAINTENANCE AND REPORT OF LSS TDM'S

REQUIREMENTS

ADVANCED TRAINING IN PROPERTIES OF METALS AND COMPOSITES FOR LSS

- ADVANCED SKILLS IN MECHANICAL, HYDRAULIC, PNEUMATIC, ELECTRICAL AVIONICS AND ELECTRONIC DIAGNOSTICS, TROUBLESHOOTING, AND REPAIR
- TRAINING IN COMPUTER HARDWARE AND SOFTWARE
- EVA PROFICIENT

Table 3.2.4-3. Crew Skill Descriptions (Continued)

JOB TITLE	WORK LOCATION
SPACECRAFT SYSTEMS OPERATIONS – DATA	IVA SPACE STATION LOCATIONS

BASIC TASKS

PERFORM ALL IVA COMPUTER REPAIR AND REFURBISHMENT TASKS

PRIMARY FUNCTION IS TO REPAIR, PERFORM MAINTENANCE AND REPLACE LRU'S, INSTALL COMPUTER EQUIPMENT UNITS, AND CABLES FOR IN-SITU AND ON-BOARD SATELLITE SERVICING AND CONSTRUCTION OPERATIONS

SECONDARY FUNCTION IS TO PROVIDE MANAGEMENT CONTROL OF DATA SERVICING EQUIPMENT, SPARES, MOD EQUIPMENT AND MAINTAIN MAINTENANCE SCHEDULES

REQUIREMENTS

ADVANCED TRAINING IN COMPUTER HARDWARE INCLUDING PERIPHERALS

ADVANCED TRAINING IN COMMUNICATIONS SYSTEMS

ADVANCED SKILLS IN ELECTRICAL AND ELECTRONIC DIAGNOSTICS, TROUBLESHOOTING AND REPAIR

EVA PROFICIENT

Table 3.2.4-3. Crew Skill Descriptions (Continued)

JOB TITLE	WORK LOCATION
SPACECRAFT SYSTEMS OPERATIONS – ELECTRONICS	IVA SPACE STATION LOCATIONS

BASIC TASKS

PERFORM ALL IVA ELECTRONIC REPAIR AND REFURBISHMENT TASKS

PRIMARY FUNCTION IS TO REPAIR, PERFORM MAINTENANCE AND REPLACE LRU'S, INSTALL ELECTRICAL EQUIPMENT UNITS FOR IN-SITU AND ON-BOARD SATELLITE SERVICING AND CONSTRUCTION AND OPERATIONS

SECONDARY FUNCTION IS TO PROVIDE MANAGEMENT CONTROL OF SERVICING EQUIPMENT, SPARES, MOD EQUIPMENT AND MAINTAIN MAINTENANCE SCHEDULES

REQUIREMENTS

INTERMEDIATE TRAINING IN ELECTRICAL POWER SYSTEMS

ADVANCED SKILLS IN ELECTRICAL DIAGNOSTICS, TROUBLESHOOTING AND REPAIR

EVA PROFICIENT

Table 3.2.4-3. Crew Skill Descriptions (Continued)

JOB TITLE	WORK LOCATION
SPACE STATION SYSTEMS OPERATION AND MAINTENANCE	SPACE STATION COMMAND CENTER

BASIC TASKS

INITIATE, PERFORM, AND COORDINATE ALL SPACECRAFT TEST AND CHECKOUT PROCEDURES REQUIRED FOR SPECIFIC SPACECRAFT DURING CONSTRUCTION MISSIONS

ESTABLISH AND MAINTAIN VOICE AND INTERACTIVE DATA LINKS BETWEEN EARTH AND GROUND STATION AND SPACECRAFT DURING TEST AND CHECKOUT

PROVIDE SUPPORT IN IN-SITU AND ON-BOARD REPAIR, REFURBISHMENT, AND SERVICING OPERATIONS, I.E.:

1. REPAIR – OBTAIN DIAGNOSTIC DATA FROM NONFUNCTIONING OR DISABLED SPACECRAFT AND ISOLATE FAULT CONDITIONS IN COORDINATION WITH GROUND CONTROL
2. REFURBISHMENT – PERFORM TEST AND CHECKOUT OF NEWLY INSTALLED SENSORS, ANTENNAS, SOLAR ARRAY, ETC.
3. SERVICING – COORDINATE TEST AND CHECKOUT PERFORMED DURING INSPACE SERVICING OF EQUIPMENT INSTALLED, REMOVED, OR TRANSFERRED ON A SCHEDULED BASIS

INITIATE, PERFORM, AND COORDINATE ALL TEST/CHECKOUT PROCEDURES REQUIRED TO SUPPORT FLIGHT SUPPORT OPERATIONS

PERFORM T&CO REQUIRED DURING OTV PREPARATION AND PRELAUNCH CHECKOUTS OF OTV AND PAYLOAD

SUPERVISE AND PERFORM SAFING, CHECKOUT, AND MAINTENANCE OPERATIONS ON RETURNING OTV'S. INCLUDE REFUELING OPERATIONS

REQUIREMENTS

ADVANCED TRAINING IN COMPUTER HARDWARE, COMMUNICATIONS SYSTEMS, ELECTRICAL SYSTEMS, MECHANICS, AND HYDRAULICS

HIGH LEVEL DIAGNOSTIC AND TROUBLESHOOTING SKILLS

APTITUDE FOR PRECISE REMOTE CONTROL OPERATIONS

EVA QUALIFIED (FOR BACKUP OPERATIONS ONLY)

MECHANICAL APTITUDE

Table 3.2.4-3. Crew Skill Descriptions (Continued)

JOB TITLE	WORK LOCATION
EVA CHERRYPICKER OPERATIONS	EVA, MANNED REMOTE WORK STATION (MRWS) ON MCP

BASIC TASKS

OPERATE/CONTROL THE MOBILE CHERRYPICKER (MCP) LOCALLY FROM THE MANNED REMOTE WORKSTATION LOCATED ON THE END OF THE CHERRYPICKER BOOM ASSEMBLY

MAINTAIN VOICE AND VISUAL CONTACT WITH OTHER EVA OR IVA CREWMAN AS REQUIRED

SUPPORT WORK PERFORMED BY EVA WORKSTATION OPERATOR

PROVIDE HANDS-ON ASSISTANCE TO ACCOMPLISH REFURBISHMENT TASKS, (I.E., REPLACE EQUIPMENT EXTERNALLY LOCATED ON THE SPACECRAFT OR MODULE BEING SERVICED)

PARTICIPATE IN OTV PAYLOAD PRELAUNCH ACTIVITIES

REMOTELY CONTROL THE MOBILE CHERRYPICKER DURING OTV CAPTURE AND BERTHING OPERATIONS

REQUIREMENTS

APTITUDE FOR PRECISE CONTROL OPERATION

EVA QUALIFIED

MECHANICAL APTITUDE

SKILLED IN USE OF HANDTOOLS

PROFICIENT AT REMOTE CONTROL

PROFICIENT AT TRANSPORTING AND POSITIONING MASSES WITH MANIPULATORS

INTERMEDIATE TRAINING IN SPACE STATION FLIGHT DYNAMICS

Table 3.2.4-3. Crew Skill Descriptions (Continued)

JOB TITLE	WORK LOCATION
EVA WORK STATIONS OPERATIONS	EVA – SELECTED WORK STATIONS
(EVA WORK STATION)	LOCATION

BASIC TASKS

PERFORM HANDS-ON MECHANICAL ASSEMBLY, DISASSEMBLY, REPAIR, AND MAINTENANCE TASKS AS REQUIRED

MAINTAIN VOICE AND VISUAL CONTACT WITH OTHER EVA AND IVA CREWMEN AS REQUIRED

SERVE AS AN OBSERVER OF OTHER EVA ACTIVITIES AND PARTICIPATE IN RESCUE OPERATIONS IF REQUIRED

PERFORM EXTERNAL INSPECTIONS OF SPACECRAFT WHICH DOCK WITH THE SPACE STATION AND CO-ORBIT WITH THE SPACE STATION

THIS CREWMAN WILL PERFORM SERVICING TASKS ON SPACECRAFT LOCATED IN A HANGAR

PERFORM WORK DURING OTV PREPARATION, OTV, AND PAYLOAD MATING AND PRELAUNCH ACTIVITIES AS REQUIRED

REQUIREMENTS

MECHANICAL APTITUDE

EVA QUALIFIED

SKILLED IN USE OF HANDTOOLS

Table 3.2.4-3. Crew Skill Descriptions (Continued)

JOB TITLE	WORK LOCATION
SPACECRAFT SYSTEMS OPERATIONS – MECHANISMS	IVA IN HABITAT MODULE COMMAND CENTER

BASIC TASKS

OPEARTE/CONTROL THE MOBILE CHERRYPICKER REMOTELY FROM THE HABITAT MODULE COMMAND CENTER

OPERATE THE TILTTABLE/TURNTABLE

OPERATE THE CONSTRUCTION FIXTURE MECHANISMS

SUPPORT EVA MCP AND EVA WORKSTATION OPERATORS AS REQUIRED

MAINTAIN VISUAL AND VOICE CONTACT WITH ALL EVA CREWMEN AND PARTICIPATE IN RESCUE OPERATIONS AS REQUIRED

SUPPORT SATELLITE REPAIR, REFURBISHMENT, AND SERVICING WORK PERFORMED ON-BOARD SPACE STATION AS REQUIRED

OPERATE UMBILICAL SYSTEM

OPERATE STORAGE FACILITY RETENSION LATCHES

OPERATE AIRLOCK SUBSYSTEMS

OPERATE TRANSPORTERS

OPERATE HANGAR DOORS, ACCESS PLATFORMS, LIGHTING, ETC.

SUPPORT OTV AND PAYLOAD MATING AND PRELAUNCH ACTIVITY AS REQUIRED

SERVE AS BACKUP MOBILE CHERRYPICKER REMOTE CONTROL OPERATOR

REQUIREMENTS

INTERMEDIATE TRAINING IN PROPERTIES OF METALS AND COMPOSITES USED IN SPACECRAFT STRUCTURES AND EQUIPMENTS

ADVANCED SKILLS IN MECHANICAL DIAGNOSTICS, TROUBLESHOOTING AND REPAIR

EVA PROFICIENT

Each member of the crew will be cross-trained to perform one or more crew jobs. As the Space Station evolves to accommodate growing mission requirements, the Space Station crew size will vary. There will be times when a 4, 5, 6, 7, 8, 9, 10, 11, or 12 person Space Station crew will be appropriate for the missions to be performed. The assumptions related to crew assignments and skills that were used to define the crew jobs are listed in Table 3.2.4-4.

Table 3.2.4-4. Assumptions Related to Crew Assignments and Skills

- THE SPACE STATION CREW ROTATION SCHEDULE AND THE SPACE STATION MISSION SCHEDULE WILL BE KNOWN FAR ENOUGH IN ADVANCE SO THAT THE PRIMARY AND BACKUP SPACE STATION CREWS CAN BE SPECIFICALLY TRAINED FOR EACH MISSION TO BE PERFORMED DURING A CREW ON-ORBIT TOUR OF DUTY
- NOMINAL ON-ORBIT STAY TIME WILL BE 90 DAYS
- NOMINAL ON-GROUND TIME BETWEEN TOURS OF DUTY WILL BE AT LEAST 6 MONTHS
- IN CONCEPT, THE TOTAL SPACE STATION CREW COULD BE CHANGED OUT AT ONE TIME. HOWEVER, IT IS MORE LIKELY THAT THERE WILL BE FRACTIONAL CREW CHANGEOUTS
- IVA CREW MEMBERS ARE CROSS-TRAINED TO PERFORM ALL EVA FUNCTIONS REQUIRED FOR THE VARIOUS SPACE STATION MISSIONS
- ALL CREW MEMBERS ARE TRAINED TO PERFORM ROUTINE SPACE STATION HOUSEKEEPING AND MAINTENANCE FUNCTIONS

The guidelines and assumptions used to create a crew daily schedule are listed in Table 3.2.4-5. The nominal work schedule selected for the Space Station crew is as follows:

- 90 DAYS TOUR OF DUTY ON-ORBIT
- 7 DAY WORK WEEK
- 6 DAYS OF WORK
  - 1 DAY OFF
- 8 HOUR WORKSHIFT
- 2 SHIFTS PER DAY (WHEN REQUIRED AND IF CREW SIZE PERMITS)

Table 3.2.4-5. Guidelines and Assumptions for Crew Work/Rest Cycles

- THE CREW WILL FOLLOW A 16-HOUR AWAKE/8-HOUR SLEEP CYCLE
- THE CREW WORKDAY IS NOMINALLY 8 HOURS
- THERE WILL BE 3/4-HOUR PER DAY SCHEDULE FOR PRE-SLEEP AND POST-SLEEP ACTIVITIES (1 – 1/2 HOURS TOTAL)
- THE CREW MEAL PERIODS WILL BE SCHEDULED FOR ONE HOUR AT LEAST TWICE PER DAY
- CREWMEN WILL SLEEP AND WORK IN SHIFTS AS REQUIRED
- PRIVATE SLEEPING QUARTERS FOR EACH CREW MEMBER IS PROVIDED. THESE SLEEPING AREAS ARE LOCATED AWAY FROM THE OPERATIONAL AREAS SO THAT OFF-DUTY CREWMEN WILL NOT BE DISTURBED
- EVA CREW WILL HAVE AN AVERAGE OF AT LEAST 10 MINUTES REST PER HOUR, PREFERABLY AFTER 50 MINUTES WORK, AND 20 MINUTES FOR LUNCH (CANDY BAR)
- CABIN CREW WORKS WHEN EVA CREW IS OUTSIDE AND COORDINATES BREAKS WITH EVA SCHEDULE
- EVA BY A SINGLE CREW MEMBER SHALL BE PERMITTED. HOWEVER, AN IVA CREW MEMBER SHALL BE AVAILABLE AT ALL TIMES TO ENGAGE IN RESCUE OPERATIONS
- NO PREBREATHING WILL BE REQUIRED FOR EVA
- NO ASSEMBLY ACTIVITIES OR EVA ACTIVITIES ARE PERFORMED DURING FLIGHT VEHICLE APPROACH AND DEPARTURE OPERATIONS

Figure 3.2.4-1 shows a typical daily schedule for the three members of a 4-person crew required to accomplish the TDMs. The fourth crew member would be involved in Space Station operations.

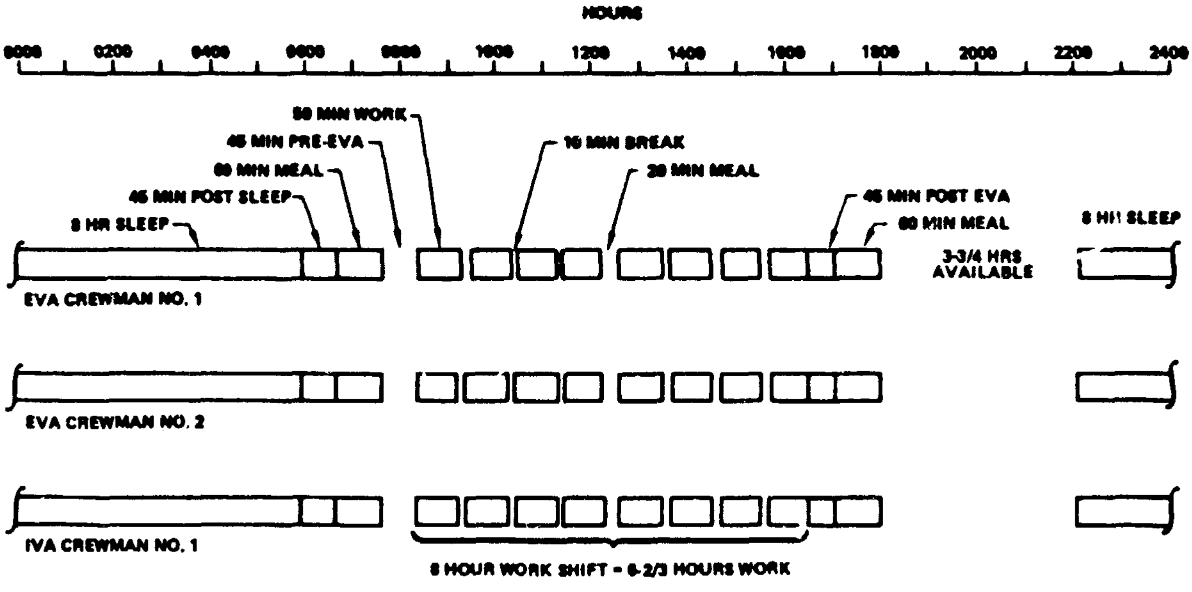
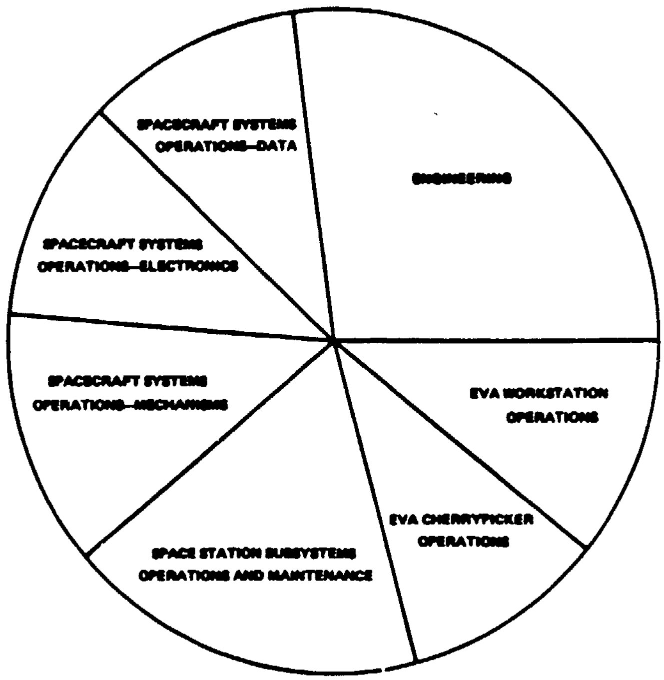
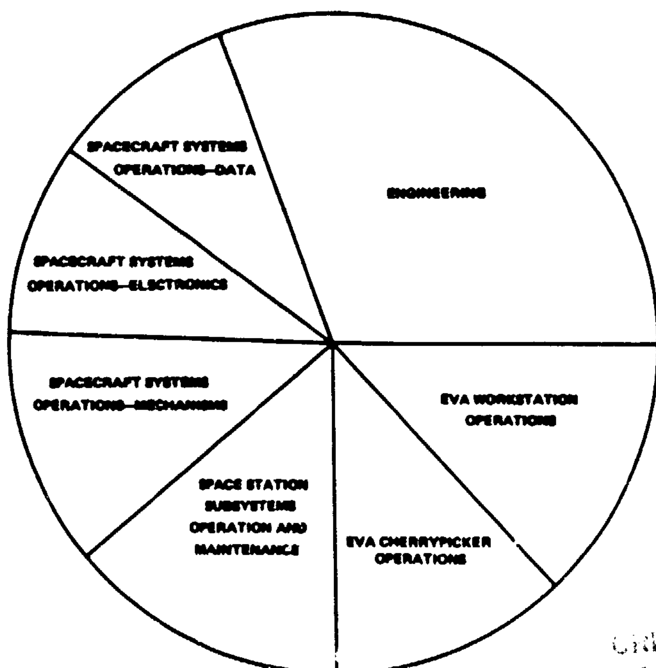


Figure 3.2.4-1. Typical LSS TDM Construction Crew Schedule (Space Station Crew of 4)

The breakdown of the percentage of each skill was made utilizing the timeline, man-machine allocation, and skills identified in the previous analysis. These crew skill requirements for each LSS TDM are presented in Figure 3.2.4-2.



CONSTRUCTION/STORAGE FACILITY (LSS-1)



SERVICING HANGAR (LSS-2)

Figure 3.2.4-2. Crew Skill Requirements

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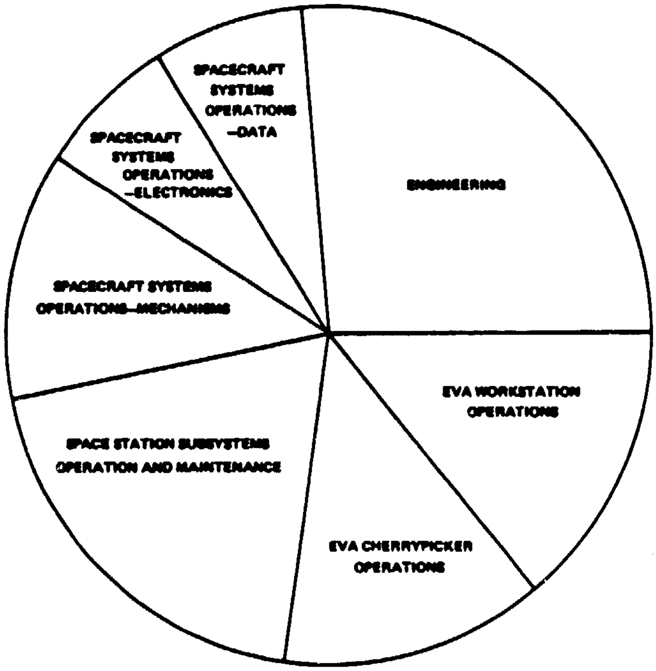
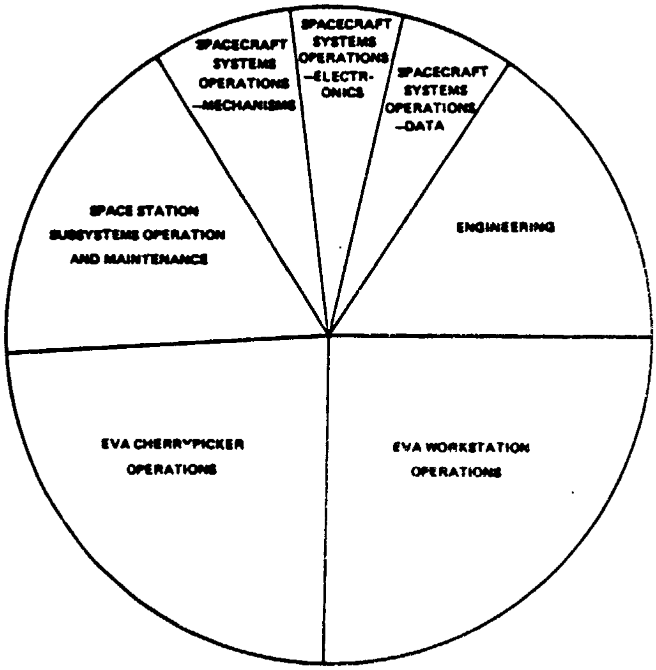


MICROWAVE RADIOMETER (LSS-3)



PRECISION OPTICAL SYSTEM (LSS-4)

Figure 3.2.4-2. Crew Skill Requirements (Continued)

3.3 Accommodation Needs From An Early Space Station

The accommodation needs of the LSS TDMs were defined by analysis of both mission and Space Station requirements/capabilities. Our Space Station experience plus the mission scenarios prepared in Section 2.1.7 provided a starting point for establishing initial and subsequent accommodation needs.

3.3.1 Operational Interfaces

The operational interfaces were defined by reviewing the construction sequence information and functional flow analysis prepared in Section 3.2.1 and man/machine allocation data from Section 3.2.2. The four LSS TDM construction sequences shown previously in Figures 3.2.1-1 through 3.2.1-4 were analyzed to identify the LSS TDM operational interfaces shown below:

Table 3.3.1-1. Operational Interfaces

- PERSONNEL
- SUPPORT FIXTURES
- INSTRUMENTATION
- DATA SYSTEMS
- UTILITIES
- HANDLING EQUIPMENT
- SMALL TOOLS

These operational interfaces are expressed in broad terms. A more detailed list is included in the definition of support equipment requirements in the next section.

3.3.2 Support Equipment

The LSS TDM accommodation needs were obtained by identifying specific support equipment required by each of the operational interfaces. The resulting list of support equipment is shown in Table 3.3.2-1 along with a more detailed list of personnel skills required.

Most of these needs are shared with other missions to be flown on the Space Station. Some support equipment, such as the precision laser ranging equipment, would be available at the Space Station from planned inventory. However, in certain instances, dedicated support equipment, such as the LSS-3 construction fixture shown in Figure 3.3.2-1, will have to be provided by individual LSS TDMs.

The postulated source of support equipment is also identified in Table 3.3.2-1.

Table 3.3.2-1. LSS TDM Accommodation Needs

	SUPPLIED BY	
	SS	TDM
• PERSONNEL		
• ENGINEERING	X	
• S/C SYSTEMS OPERATIONS – DATA	X	
• S/C SYSTEMS OPERATIONS – ELECTRONICS	X	
• S/C SYSTEMS OPERATIONS – MECHANISMS	X	
• SPACE STATION SUBSYSTEM OPERATIONS AND MAINT	X	
• EVA CHERRYPICKER OPERATIONS	X	
• EVA WORKSTATION OPERATIONS	X	
• SUPPORT FIXTURES		
• STORAGE FACILITY	X	
• CONSTRUCTION FIXTURES		X
• MISCELLANEOUS CONSTRAINTS AND HOLD-DOWNS	X	
• S/C ORIENTATION FIXTURE		X
• ARTICULATED HOLDING FIXTURE (LASER MEAS.)	X	
• DOCKING/BERTHING PORT	X	
• STRUT ALIGNMENT AND ASSEMBLY FIXTURE		X
• INSTRUMENTATION		
• STRUCTURAL DYNAMICS (ACCEL., STRAIN, LOADS, ETC.)		X
• THERMAL RESPONSE (THERMOCOUPLES)		X
• POSITION/DEFLECTION (PRECISION LASER RANGING, CORNER REFLECTORS)	X	X
• DATA SYSTEMS		
• RECORDING	X	
• STORAGE AND RETRIEVAL	X	
• MANIPULATION (EDP)	X	
• TRANSMISSION (UPLINK AND DOWNLINK)	X	
• UTILITIES		
• ELECTRICAL POWER	X	
• LIGHTING	X	
• REMOTE TV	X	
• HANDLING EQUIPMENT		
• RMS (CHERRYPICKER)	X	
• SMALL TOOLS		
• MAINTENANCE	X	
• CONSTRUCTION	X	X

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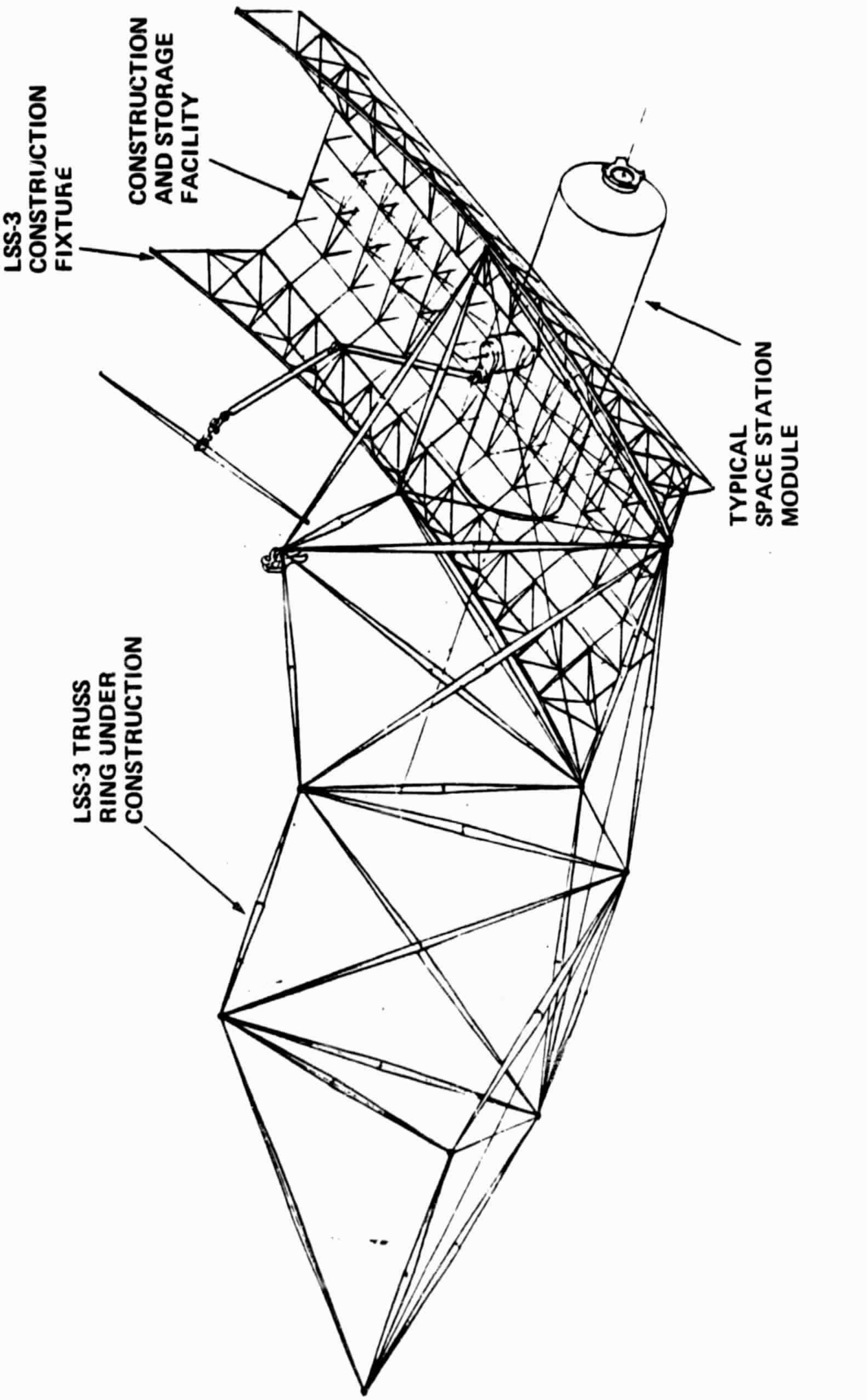

Figure 3.3.2-1. LSS-3 Construction Fixture

4.0 PROGRAMMATIC ANALYSIS

Programmatic analysis provides the necessary plans, schedules and cost analysis to support the definition of the technology development missions. This is necessary to insure that programmatic issues are given proper consideration in the development and analysis of the missions. Programmatic analysis was performed in two subtasks: (1) plans and schedules and (2) cost analysis.

4.1 Plans and Schedules

The development of plans and schedules for the TDMs involves five objectives: (1) identify precursor technology developments, (2) define critical items and sensitivities, (3) define risks, (4) define schedules and (5) prepare preliminary plans for the selected missions. Each of these objectives is addressed in the following subsections.

4.1.1 Precursor Technology Requirements

Precursor technology developments that are necessary for the implementation of the LSS technology development missions can be catagorized in two classes: (1) precursor technology developments of general-purpose support equipment and operations that are not dedicated to the LSS missions and (2) precursor LSS TDM capabilities demonstrations.

The technology advancement of general purpose support equipment and operations that are not dedicated to the LSS missions that can and should be accomplished using ground tests and Shuttle flights are shown in Table 4.1.1-1. These capabilities are useful for a wide range of applications on the Space Station.

Table 4.1.1-1. Precursor Equipment and Operations Not Dedicated to LSS

DEVELOPMENTS NECESSARY FOR LSS TDM	TESTS		
	GROUND	NEUTRAL BUOYANCY	SHUTTLE
CHERRYPICKER/RMS	X		X
EVA ASSEMBLY OPERATIONS CAPABILITY	X	X	X
DYNAMIC TESTING	X		X
SURFACE ACCURACY MEASUREMENT	X		X
MODAL IDENTIFICATION TECHNIQUES	X		X

The precursor LSS TDM equipment and operations that can and should be accomplished using ground tests and Shuttle flights are shown in Table 4.1.1-2.

These precursor equipments and operations were identified during the definition of the technology development missions and mission operations analysis.

Table 4.1.1-2. Precursor LSS TDM Equipment and Operations

DEVELOPMENTS NECESSARY FOR LSS TDM	TESTS		
	GROUND	NEUTRAL BUOYANCY	SHUTTLE
ASSEMBLABLE JOINT	X	X	X
FOLDING DEPLOYABLE JOINT	X	X	X
MRS REFLECTIVE MEMBRANE SURFACE	X		X
MRS MEMBRANE SURFACE CONTOUR MEASURING SYSTEM	X		X
MRS MEMBRANE TENSIONING SYSTEM	X		X
MIRROR POSITIONING CONTROLS	X		X
DEPLOYABLE TRUSS BEAMS	X	X	X
TENSION STABILIZED BEAMS	X		X

4.1.2 Critical Items and Sensitivities

The critical items that are potential risks to the accomplishment of the LSS TDMs are shown in Table 4.1.2-1.

Table 4.1.2-1. Major Risk Elements

<u>LSS-1</u>

- DEPLOYMENT DYNAMICS
  - FOLDING DEPLOYABLE JOINT
  - RATE OF DEPLOYMENT
- DYNAMIC EFFECTS ON SPACE STATION
- EVA CREW SAFETY DURING DEPLOYMENT

<u>LSS-2</u>

- ALIGNMENT OF TOP JOINT
- DEPLOYABLE TRUSS BEAMS
- RETRACTION OF HANGAR PANELS

<u>LSS-3</u>

- DYNAMIC EFFECTS ON SPACE STATION
  - PARTIALLY ASSEMBLED RING
- RING ADVANCEMENT MECHANISMS
- REFLECTIVE MEMBRANE SURFACE
- SURFACE ADJUSTMENT MECHANISM
- CONTOUR MEASURING SYSTEM

<u>LSS-4</u>

- DYNAMIC EFFECTS ON SPACE STATION
- MIRROR POSITIONING SYSTEM
- MIRROR ALIGNMENT SENSING SYSTEM

The crew safety item listed for LSS-1 applies also to all other TDMs as well. Most of the risks can be significantly reduced by the ground and Shuttle tests shown previously in Tables 4.1.1-1 and 4.1.1-2.

4.1.3 Risk Assessment

No "show-stoppers" have been identified for the LSS technology development missions during this study. While there are a number of technology items that must be developed and/or improved, no items were identified that could not reach their required readiness level within the available time and at a reasonable cost.

The major risk items identified are associated with the interaction of large space structures with the Space Station. LSS dynamics/control interaction during construction

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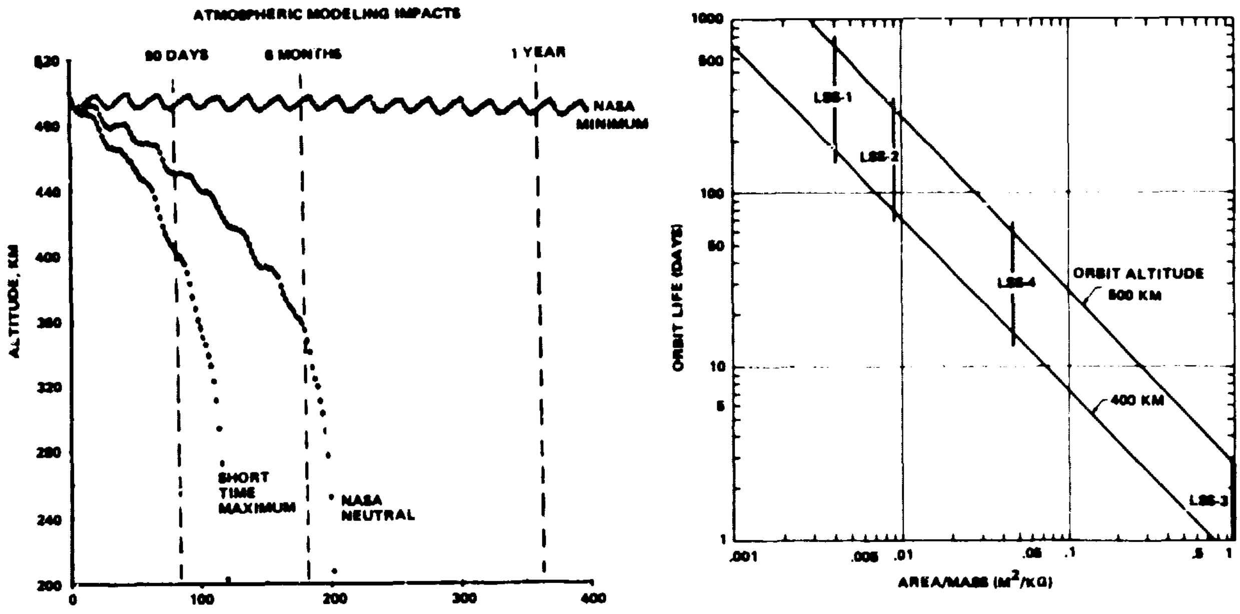
is potentially significant and must be fully understood to assure structural integrity and crew safety.

Another identified risk concerns LSS construction using multiple STS flights without a Space Station. Without a Space Station or platform to provide orbit maintenance and stationkeeping, the orbital lifetimes of spacecraft in low Earth orbit can be very short depending upon its area-to-mass ratio. Figure 4.1.3-1 shows the effect of atmospheric density and area-to-mass ratio on orbit lifetimes. The left hand figure shows calculated orbital lifetimes using various atmosphere models with a spacecraft in a 500 km orbit. The spacecraft analyzed has an area-to-mass ratio of 0.014. The orbital decay is inversely proportional to A/M and curves of orbit lifetime vs A/M are plotted for 400 and 500 km orbital altitudes in the right hand figure. The A/M values associated with the four TDM's are indicated on the figure. It can be seen that, if left unattended, the orbits will decay rather rapidly and will complicate revisit procedures. The large area of LSS-3, the microwave radiometer, results in an orbit lifetime from less than one day to approximately three days depending on the altitude.



• AREA/MASS = .014
• NO STATION KEEPING

• NASA NEUTRAL ATMOSPHERE

Figure 4.1.3-1. Orbital Lifetime Estimates

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4.1.4 Mission Schedules

A detailed schedule for each LSS TDM was developed, including design and development, manufacturing, preliminary tests, flight-readiness verification, shuttle operations, space station operations, return of the mission equipment to Earth as appropriate, and transitioning to full operational capability for large space structures on future missions.

The preliminary LSS TDM program master schedules showing anticipated go-ahead, design and development, manufacturing, test, flight-readiness verification, ground operations, launch, and Space Station operations, are given in Figure 4.1.4-1 with a scheduled launch in 1991 for LSS-1 and 2, 1993 for LSS-4, and 1996 for LSS-3.

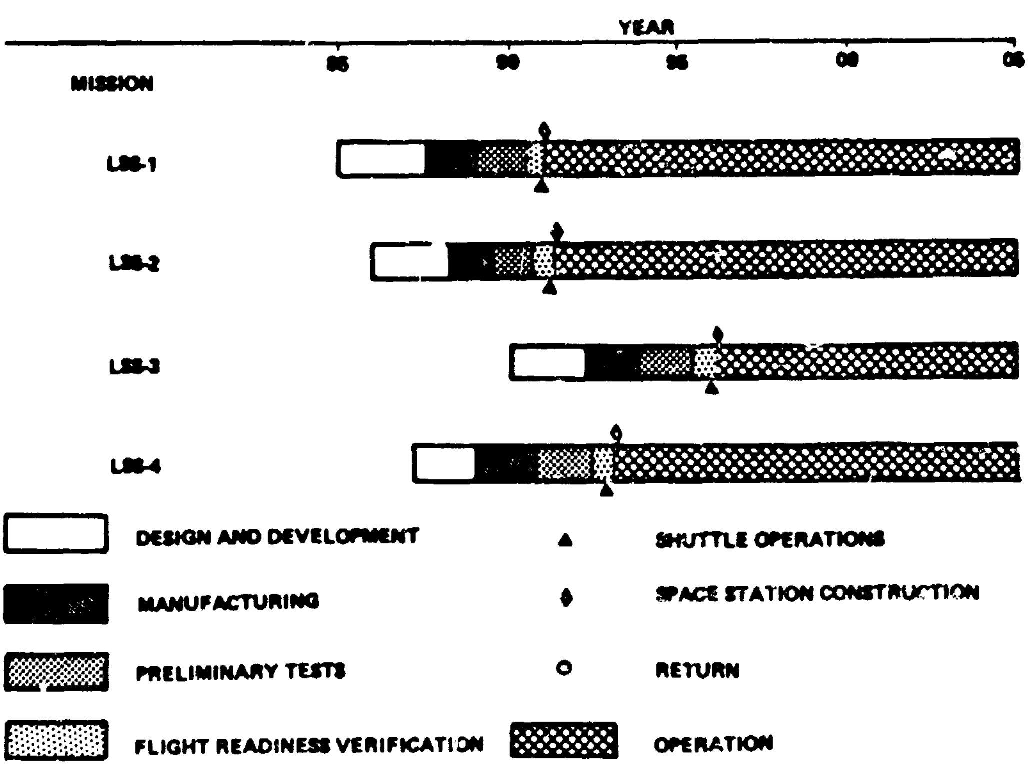

Figure 4.1.4-1. LSS TDM Schedule

4.1.5 Mission Plans

Mission data forms were prepared for each LSS TDM. These forms were derived from the preceding technology development mission analysis and serve as stand-alone mission plans for each TDM. The information included on these forms includes (1) mission description with objectives and benefits, (2) mission launch date, (3) support equipment and space station facilities, (4) crew skills required, (5) manloading and (6) mission costs. The four mission data forms are shown in Figures 4.1.5-1 through 4.1.5-4.

4.2 Mission Cost Analysis

An analysis of each TDM was conducted to determine the costs associated with its development, manufacture, transportation and orbital operations. TDM costs were determined using the cost data base we have developed on our previous spacecraft and Space Station studies to price the various hardware and operations. This operations cost data base includes spacecraft hardware and development costs, transportation costs per kilogram, resupply costs per kilogram, crew costs per man-day, etc. New equipment hardware and development costs were defined using the Boeing Parametric Cost Model (PCM) cost analysis computer model and the RCA PRICE hardware acquisition model.

The cost groundrules provided by MSFC are listed below.

- Cost estimates are in FY-84 dollars, including fiscal year funding requirements.

- Space Station ATP are FY-86 with initial launch in FY-90 and IOC in FY-91.

- Cost estimates include all requirements unique to demonstrating the technology feasibility including:

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PAYLOAD ELEMENT NAME
CONST & STORAGE FAC (LSS-1)

CODE
FACX2037

TYPE
( ) Science and Applications (Non-comm.)
( ) Commercial
(X) Technology Development
( ) Operations
( ) Other
( ) National Security
Type number (see table A) 10

CONTACT
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PO BOX 3999
SEATTLE, WA 98124

Telephone 206/773-2020

Importance of the Space Station to this Element
1 = Low Value, But Could Use
10 = Vital
Scale = 8

STATUS
( ) Operational ( ) Approved ( ) Planned (X) Candidate ( ) Opportunity

Desired First Flight, Year: 1991 Number of Flights 1 Duration of Flight, Days 365

OBJECTIVE
LARGE SPACE STRUCTURES TECHNOLOGY
DEMONSTRATIONS (DEPLOYMENT AND ASSEMBLY , SUBSYSTEM INSTALLATION AND CHECKOUT, DEMONSTRATION OF MAN'S ROLE AND CAPABILITIES IN SPACE). FOLLOWING THE TDM, THIS STRUCTURE WILL SERVE AS A PERMANENT SPACE STATION FACILITY.

DESCRIPTION
THE CONSTRUCTION AND STORAGE FACILITY IS A LARGE PLANAR, DEPLOYABLE TRUSS ATTACHED TO THE SPACE STATION AT A BERTHING PORT. ADDITIONAL STRUCTURAL SUPPORT STRUCTURES WILL BE ATTACHED TO PROVIDE STRUCTURAL ATTACHMENTS FOR PAYLOADS AND OTHER MODULES TRANSPORTED TO THE SPACE STATION VIA STS.

ORBIT CHARACTERISTICS
Geosynchronous Orbit ( ) Yes (X) No
Apogee, km 500 Perigee, km 500 Tolerance + -
Inclination, deg 28.5 Tolerance + -
Nodal Angle, deg Any Ephemeris Accuracy, m
Escape dV Required, m/s

POINTING/ORIENTATION
View Direction ( ) Inertial ( ) Solar ( ) Earth (X) Any
Truth Sites (if known)
Pointing Accuracy, arc-sec 0.00 Field of View (deg)
Pointing Stability (Jitter), arc-sec/sec 0.00
Special Restrictions (Avoidance)

POWER
( ) AC ( ) DC

	Power, W	Duration, Hrs/Day	
Operating	0	0.00	
Standby	0	0.00	(X) Continuous
Peak	0	0.00	
Voltage, V	0	Frequency, Hz	0

Figure 4.1.5-1. Mission Data Form, LSS-1

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DATA/COMMUNICATIONS
Monitoring Requirements:
( ) None (X) Realtime ( ) Offline ( ) Other:
( ) Encription/Decription Required
( ) Uplink Required: Command Rate (KBS): 0 Frequency (MHz): 0.00
( ) On-Board Data Processing Required
Description:
Data Types: ( ) Analog ( ) Digital Hours/Day 0.00
Film (Amount): 0 Voice (Hours/Day): 0.00
Live TV (Hours/Day): 0.00 Other:
On-Board Storage (Mbit): 0.00
Data Dump Frequency (Per Orbit) 0 Downlink command rate: 0
Recording Rate (KBPS) 0.00 Downlink Frequency (MHz): 0.00

THERMAL
( ) Active (X) Passive

Temperature, deg C	Operational Minimum	0	Maximum	0
	Non-operational Minimum	0	Maximum	0
Heat Rejection, W	Operational Minimum	0	Maximum	0
	Non-operational Minimum	0	Maximum	0

EQUIPMENT PHYSICAL CHARACTERISTICS
Location ( ) Internal (X) External ( ) Remote
Equipment ID/Function ( ) Pressurized (X) Unpressurized
Length: 2.50 meters Width: 2.50 meters Height: 2.00 meters (Stowed)
Length: 26.00 meters Width: 12.00 meters Height: 3.50 meters (Deployed)
Launch mass, kg: 2600 Return mass, kg:
Consumable Types
Acceleration Sensitivity, (g) min: 0.00E+00 max: 0.00E+00

CREW REQUIREMENTS
Crew Size 0

Task Assignments

Skills (See Table B)

Skill	11	12	13			
Level	3	3	3			
Hours/Day	0.00	0.00	0.00			

EVA (X) Yes ( ) No Reason CONSTRUCTION Hours/EVA 120

SERVICING/MAINTENANCE
Service: Interval 0 days Consumables 0 kg
Returnables 0 kg Man hours required 0.00
Configuration Changes: Interval 0 days Man/Hours Required 0.00
Deliverables 0 kg Returnables 0 kg

SPECIAL CONSIDERATIONS/See instructions
AS A TECHNOLOGY DEMONSTRATION MISSION (TDM), REALTIME MONITORING (TV) AND DATA MEASUREMENT EQUIPMENT (STRUCTURAL ACCURACY, DYNAMICS, THERMAL DEFLECTIONS) WILL BE REQUIRED. FOLLOWING THE TDM, PERMANENTLY MOUNTED TV AND AUXILIARY LIGHTING ARE REQUIRED.

Figure 4.1.5-1. Mission Data Form, LSS-1 (Continued)

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-----------------------------------------------------------------------------------------
                              Boeing-Specific Input Data
-----------------------------------------------------------------------------------------
MISSION TYPE                                     OPS CODE
   Free Flyer
   ( ) Not Serviced                                 F
   ( ) Remote THS                                   FT
   ( ) Remote Manned                                FM
   ( ) Serviced at Station (THS Retrieved)          FST
   ( ) Serviced at Station (Self-propelled)         FS

   Platform Based
   ( ) Not Serviced                                 P
   ( ) Remote THS                                   PT
   ( ) Remote Manned                                PM
   ( ) Serviced at Station (THS Retrieved)          PST
   ( ) Serviced at Station (Self-propelled)         PS

   Other
   (X) Space Station Based                          SS
   ( ) Sortie                                       SOR

CONSTRUCTION/SERVICING COMPLEXITY
   (X) Low
   ( ) Medium
   ( ) High

Operations Times
   OTV Up/Down                      0 days
   OTV or THS on Orbit              0 days
   Mission Use                    365 days/year
   IVA Service                     10 man-days/year
   EVA Service                     20 man-days/year
   Experiment Ops                  20 man-days/year
   Service Frequency                4 times/year

Delta Velocities
   Up                      0.00
   Down                    0.00
   Aero Return             0.00

Support Equipment
             Length:       1.00 meters     Width:      .50 meters     Height:     .50 meters    (Stowed)
             Length:       3.00 meters     Width:     1.00 meters     Height:    1.00 meters    (Deployed)

             Mass:         100 kg

Manifest Restrictions
   (X) No Restrictions
   ( ) Only with compatible payloads
   ( ) Fly-Alone
   ( ) Must have Docking Module

Length of Beam Fab                                       0.00
Number of Appendages                                     120
Number of Modules Required to Assemble the Payload         2
-----------------------------------------------------------------------------------------
```

Figure 4.1.5-1. Mission Data Form, LSS-1 (Continued)

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PAYLOAD ELEMENT NAME
SPACECRAFT HANGAR (LSS-2)

CODE
BACX2034

TYPE
( ) Science and Applications (Non-comm.)
( ) Commercial
(X) Technology Development
( ) Operations
( ) Other
( ) National Security
Type number (see table A) 10

CONTACT
Name RICHARD GATES
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PO BOX 3999
SEATTLE, WA 98124

Telephone (206) 773-2020

Importance of the Space Station to this Element
1 = Low Value, But Could Use
10 = Vital
Scale = 8

STATUS
( ) Operational ( ) Approved ( ) Planned (X) Candidate ( ) Opportunity

Desired First Flight, Year: 1991 Number of Flights 1 Duration of Flight, Days 365

OBJECTIVE
LARGE SPACE STRUCTURES TECHNOLOGY DEMONSTRATIONS (DEPLOYMENT AND ASSEMBLY, SUBSYSTEM INSTALLATION AND CHECKOUT, DEMONSTRATION OF MAN'S ROLE AND CAPABILITIES IN SPACE). FOLLOWING THE TDM, THIS STRUCTURE WILL SERVE AS A PERMANENT SPACE STATION FACILITY.

DESCRIPTION
THE SPACECRAFT HANGAR FACILITY IS A DEPLOYABLE OR ASSEMBLABLE STRUCTURE TO PROVIDE SOLAR RADIATION AND MICROMETERIORITE PROTECTION FOR PERSONNEL, SPACECRAFT AND OTV'S WHILE SERVICING IS BEING PERFORMED. ELECTRICAL POWER AND LIGHTING WILL BE PROVIDED AS WELL AS CONTAINMENT FOR TOOLS, PARTS & PERSONNEL.

ORBIT CHARACTERISTICS
Geosynchronous Orbit ( ) Yes (X) No
Apogee, km 500 Perigee, km 500 Tolerance + -
Inclination, deg 28.5 Tolerance + -
Nodal Angle, deg Any Ephemeris Accuracy, m
Escape dV Required, m/s

POINTING/ORIENTATION
View Direction ( ) Inertial ( ) Solar ( ) Earth (X) Any
Truth Sites (if known)
Pointing Accuracy, arc-sec Field of View (deg)
Pointing Stability (Jitter), arc-sec/sec
Special Restrictions (Avoidance)

POWER
( ) AC (X) DC

	Power, W	Duration, Hrs/Day
Operating	500	
Standby		(X) Continuous
Peak		

Figure 4.1.5-2. Mission Data Form, LSS-2

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Voltage, V Frequency, Hz

DATA/COMMUNICATIONS
Monitoring Requirements:
( ) None (X) Realtime ( ) Offline ( ) Other:
( ) Encription/Decription Required
( ) Uplink Required: Command Rate (KBS): Frequency (MHz):
( ) On-Board Data Processing Required
Description:
Data Types: ( ) Analog ( ) Digital Hours/Day
Film (Amount): Voice (Hours/Day):
Live TV (Hours/Day): Other:
On-Board Storage (Mbit):
Data Dump Frequency (Per Orbit) Downlink command rate:
Recording Rate (KBPS) Downlink Frequency (MHz):

THERMAL
( ) Active (X) Passive
Temperature, deg C Operational Minimum Maximum
Non-operational Minimum Maximum
Heat Rejection, w Operational Minimum Maximum
Non-operational Minimum Maximum

EQUIPMENT PHYSICAL CHARACTERISTICS
Location ( ) Internal (X) External ( ) Remote
Equipment ID/Function ( ) Pressurized (X) Unpressurized
Length: 1.00 meters Width: 4.6 meters Height: 4.00 meters (Stowed)
Length: 26.00 meters Width: 12.00 meters Height: 9.50 meters (Deployed)
Launch mass, kg: 550 Return mass, kg.
Consumable types
Acceleration Sensitivity, (g) min: 0.00E+00 max: 0.00E+00

CREW REQUIREMENTS
Crew Size Task Assignments

Skills (See Table B)

Skill	11	12	13			
Level	3	3	3			
Hours/Day						

EVA (X) Yes ( ) No Reason CONSTRUCTION Hours/EVA 120

SERVICING/MAINTENANCE
Service: Interval days Consumables kg
Returnables kg Man hours required
Configuration Changes: Interval days Man/Hours Required
Deliverables kg Returnables kg

SPECIAL CONSIDERATIONS/See instructions
AS A TECHNOLOGY DEMONSTRATION MISSON (TDM), REALTIME MONITORING (TV) AND DATA MEASUREMENT EQUIPMENT (STRUCTURAL DYNAMICS, THERMAL DEFLECTIONS) WILL BE REQUIRED. FOLLOWING THE TDM, SYSTEM STATUS (RETRACTED/DEPLOYED/LATCHED) INSTRUMENTATION WILL BE REQUIRED.

Figure 4.1.5-2. Mission Data Form, LSS-2 (Continued)

Boeing-Specific Input Data

MISSION TYPE	OPS CODE
Free Flyer	
( ) Not Serviced	F
( ) Remote TMS	FT
( ) Remote Manned	FM
( ) Serviced at Station (TMS Retrieved)	FST
( ) Serviced at Station (Self-propelled)	FS
Platform Based	
( ) Not Serviced	P
( ) Remote TMS	PT
( ) Remote Manned	PM
( ) Serviced at Station (TMS Retrieved)	PST
( ) Serviced at Station (Self-propelled)	PS
Other	
(X) Space Station Based	SS
( ) Sortie	SOR

CONSTRUCTION/SERVICING COMPLEXITY

( ) Low
(X) Medium
( ) High

Operations Times	
OTV Up/Down	0 days
OTV or TMS on Orbit	0 days
Mission Use	365 days/year
IVA Service	10 man-days/year
EVA Service	20 man-days/year
Experiment Ops	48 man-days/year
Service Frequency	4 times/year

Delta Velocities

Up
Down
Aero Return

Support Equipment

Length:	meters	Width:	meters	Height:	meters	(Stowed)
Length:	meters	Width:	meters	Height:	meters	(Deployed)
Mass:	kg					

Manifest Restrictions

(X) No Restrictions
( ) Only with compatible payloads
( ) Fly-Alone
( ) Must have Docking Module

Length of Beam Fab
Number of Appendages
Number of Modules Required to Assemble the Payload 16

Figure 4.1.5-2. Mission Data Form, LSS-2 (Continued)

```
PAYLOAD ELEMENT NAME                CODE                                TYPE
PASSIVE MW RADIOM (LSS-3)           BACX2001               ( ) Science and Applications (Non-comm.)
                                                                   ( ) Commercial
CONTACT                                                            (X) Technology Development
Name      RICHARD GATES                                            ( ) Operations
Address   BOEING AEROSPACE CO                                      ( ) Other
          PO BOX 3999                                              ( ) National Security
          SEATTLE, WA  98124                                       Type number (see table A)  10

Telephone  206/773-2020                                            Importance of the Space Station to
                                                                   this Element
STATUS                                                             1  = Low Value, But Could Use
 ( ) Operational  ( ) Approved  ( ) Planned  (X) Candidate  ( ) Opportunity   10 = Vital
                                                                   Scale = 10

Desired First Flight, Year: 1996     Number of Flights    1     Duration of Flight, Days   0

OBJECTIVE
LARGE SPACE STRUCTURES TECHNOLOGY DEMONSTRATIONS: DEPLOYMENT AND
ASSEMBLY, SUBSYSTEM INSTALLATION AND CHECKOUT, DEMONSTRATE MAN'S ROLE
AND CAPABILITIES IN SPACE, DEPLOYMENT OR INSTALLATION OF MEMBRANE
SURFACE, SYSTEM IDENTIFICATION, ADAPTIVE CONTROL, ANTENNA TESTING,
STRUCTURAL DYNAMICS, THERMAL CONTROL, SURFACE MANAGEMENT AND
CONTROL, DAMPING AUGMENTATION, AND POINTING CONTROL.

DESCRIPTION
ASSEMBLE THE PASSIVE MICROWAVE RADIOMETER SATELLITE. DURING THE ASSEMBLY, THIS SPACECRAFT WOULD BE
INSTRUMENTED AND TESTED TO DEMONSTRATE THE VARIOUS TECHNOLOGIES DEFINED ABOVE. AFTER TECH
DEMOS ARE COMPLETED, THIS SPACECRAFT WOULD BE MOVED TO ITS DESIRED LOCATION AND MADE OPERATIONAL.

ORBIT CHARACTERISTICS
   Geosynchronous Orbit       ( ) Yes      (X) No
   Apogee, km       >600             Perigee, km     >600      Tolerance    +      -
   Inclination, deg           60                               Tolerance    +      -
   Nodal Angle, deg           Any                              Ephemeris Accuracy, m
   Escape dV Required, m/s

POINTING/ORIENTATION
   View Direction              ( ) Inertial   ( ) Solar     (X) Earth      ( ) Any
   Truth Sites (if known)
   Pointing Accuracy, arc-sec          36.               Field of View (deg)  1
   Pointing Stability (Jitter), arc-sec/sec
   Special Restrictions (Avoidance)

POWER
   ( ) AC          ( ) DC
                   Power, W          Duration, Hrs/Day

   Operating         500
   Standby                                           (X) Continuous
   Peak
   Voltage, V                        Frequency, Hz
```

Figure 4.1.5-3. Mission Data Form, LSS-3

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DATA/COMMUNICATIONS
Monitoring Requirements:
( ) None (X) Realtime (X) Offline ( ) Other:
( ) Encription/Decription Required
(X) Uplink Required: Command Rate (KBS): Frequency (MHz):
(X) On-Board Data Processing Required
Description:
Data Types: ( ) Analog ( ) Digital Hours/Day
Film (Amount): Voice (Hours/Day):
Live TV (Hours/Day): Other:
On-Board Storage (Mbit):
Data Dump Frequency (Per Orbit) Downlink command rate:
Recording Rate (KBPS) Downlink Frequency (MHz):

THERMAL
( ) Active (X) Passive
Temperature, deg C Operational Minimum Maximum
Non-operational Minimum Maximum
Heat Rejection, w Operational Minimum Maximum
Non-operational Minimum Maximum

EQUIPMENT PHYSICAL CHARACTERISTICS
Location ( ) Internal (X) External (X) Remote
Equipment ID/Function ( ) Pressurized (X) Unpressurized
Length: 13 meters Width: 4 meters Height: 4 meters (Stowed)
Length: 104 meters Width: 104 meters Height: 90 meters (Deployed)
Launch mass, kg: 7355 Return mass, kg:
Consumable Types PROPELLANT
Acceleration Sensitivity, (g) min: 0.00E+00 max: 0.00E+00

CREW REQUIREMENTS
Crew Size Task Assignments

Skills (See Table B)

Skill	12	13	7	8	9		
Level	3	3	3	3	3		
Hours/Day							

EVA (X) Yes ( ) No Reason CONSTRUCTION Hours/EVA 888

SERVICING/MAINTENANCE
Service: Interval days Consumables kg
Returnables kg Man hours required
Configuration Changes: Interval days Man/Hours Required
Deliverables kg Returnables kg

SPECIAL CONSIDERATIONS/See instructions
SURFACE ACCURACY REQUIREMENT WAVELENGTH/50
MICROWAVE FREQUENCY <5 GHZ

Figure 4.1.5-3. Mission Data Form, LSS-3 (Continued)

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Boeing-Specific Input Data

MISSION TYPE		OPS CODE
Free Flyer		
(X) Not Serviced		F
( ) Remote TMS		FT
( ) Remote Manned		FM
( ) Serviced at Station	(TMS Retrieved)	FST
( ) Serviced at Station	(Self-propelled)	FS
Platform Based		
( ) Not Serviced		P
( ) Remote TMS		PT
( ) Remote Manned		PM
( ) Serviced at Station	(TMS Retrieved)	PST
( ) Serviced at Station	(Self-propelled)	PS
Other		
( ) Space Station Based		SS
( ) Sortie		SOR

CONSTRUCTION/SERVICING COMPLEXITY
( ) Low
( ) Medium
(X) High

Operations Times
OTV Up/Down 0 days
OTV or TMS on Orbit days
Mission Use 365 days/year
IVA Service 10 man-days/year
EVA Service 20 man-days/year
Experiment Ops 148 man-days/year
Service Frequency 4 times/year

Delta Velocities
Up
Down
Aero Return

Support Equipment
Length: 2.5 meters Width: 2.5 meters Height: 1 meters (Stowed)
Length: 26 meters Width: 12 meters Height: 3.5 meters (Deployed)

Mass: 2000 kg

Manifest Restrictions
(X) No Restrictions
( ) Only with compatible payloads
( ) Fly-Alone
( ) Must have Docking Module

Length of Beam Fab
Number of Appendages
Number of Modules Required to Assemble the Payload

Figure 4.1.5-3. Mission Data Form, LSS-3 (Continued)

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PAYLOAD ELEMENT NAME
PRECISION OPTICAL SYSTEM (LSS-4)

CODE
BACX2036

TYPE
( ) Science and Applications (Non-comm.)
( ) Commercial
(X) Technology Development
( ) Operations
( ) Other
( ) National Security
Type number (see table A) 10

CONTACT
Name RICHARD GATES
Address BOEING AEROSPACE CO
PO BOX 3999
SEATTLE, WA 98124

Telephone 206/773-2020

Importance of the Space Station to this Element
1 = Low Value, But Could Use
10 = Vital
Scale = 10

STATUS
( ) Operational ( ) Approved ( ) Planned (X) Candidate ( ) Opportunity

Desired First Flight, Year. 1993 Number of Flights 1 Duration of Flight, Days 365

OBJECTIVE
LARGE APERTURE IR ASTRONOMY FACILITY AND LARGE SPACE STRUCTURES TECHNOLOGY DEMONSTRTION MISSION (DEPLOYMENT AND ASSEMBLY, ASSEMBLY OF HIGH-PRECISION RIGID STRUCTURE, SUBSYSTEM INSTALLATION AND CHECKOUT, PRECISION CONTROL OF LSS, ADAPTIVE OPTICS, DEMONSTRATE MAN'S ROLE AND CAPABILITIES, SYSTEM IDENTIFICATION, SEGMENTED MIRRORS).

DESCRIPTION
THIS IS A LARGE AMBIENT IR TELESCOPE THAT IS ASSEMBLED FROM MODULES (PRIMARY MIRROR SEGMENTS, STRUCTURAL MODULES, SECONDARY MIRROR ASSEMBLY, INSTRUMENTATION MODULE, SOLAR ARRAYS, RADIATORS, PROPULSION TANKS, ETC.). AFTER ASSEMBLY, SYSTEM TESTS, TECHNOLOGY DEMO TESTS, ETC, ARE COMPLETED THIS TELESCOPE WOULD BE TRANSFERRED TO AN ORBITAL POSITION WHERE IT WOULD THEN BE REMOTELY OPERATED FROM A GROUND STATION.

ORBIT CHARACTERISTICS
Geosynchronous Orbit ( ) Yes (X) No
Apogee, km 500 Perigee, km 500 Tolerance + -
Inclination, deg 28.5 Tolerance + -
Nodal Angle, deg Any Ephemeris Accuracy, m
Escape dV Required, m/s

POINTING/ORIENTATION
View Direction (X) Inertial ( ) Solar ( ) Earth ( ) Any
Truth Sites (if known)
Pointing Accuracy, arc-sec Field of View (deg)
Pointing Stability (Jitter), arc-sec/sec
Special Restrictions (Avoidance)

POWER
(X) AC (X) DC

	Power, W	Duration, Hrs/Day
Operating	500	
Standby		(X) Continuous
Peak		

Figure 4.1.5-4. Mission Data Form, LSS-4

Voltage, V Frequency, Hz

DATA/COMMUNICATIONS
Monitoring Requirements:
( ) None (X) Realtime (X) Offline ( ) Other:
( ) Encription/Decription Required
(X) Uplink Required: Command Rate (KBS): Frequency (MHz):
( ) On-Board Data Processing Required
Description:
Data Types: ( ) Analog (X) Digital Hours/Day
Film (Amount): Voice (Hours/Day):
Live TV (Hours/Day): Other:
On-Board Storage (Mbit):
Data Dump Frequency (Per Orbit) Downlink command rate:
Recording Rate (KBPS) Downlink Frequency (MHz):

THERMAL
(X) Active ( ) Passive
Temperature, deg C Operational Minimum Maximum
Non-operational Minimum Maximum
Heat Rejection, w Operational Minimum Maximum
Non-operational Minimum Maximum

EQUIPMENT PHYSICAL CHARACTERISTICS
Location ( ) Internal ( ) External (X) Remote
Equipment ID/Function ( ) Pressurized ( ) Unpressurized
Length: 5.00 meters Width: 4.50 meters Height: 4.50 meters (Stowed)
Length: 12.00 meters Width: 12.00 meters Height: 28.0 meters (Deployed)
Launch mass, kg: 5060 Return mass, kg:
Consumable Types
Acceleration Sensitivity, (g) min: 0.00E+00 max: 0.00E+00

CREW REQUIREMENTS
Crew Size 8

Skills (See Table B)

Task Assignments

Skill	11	12	13			
Level	3	3	3			
Hours/Day						

EVA (X) Yes ( ) No Reason CONSTRUCTION Hours/EVA 84.00

SERVICING/MAINTENANCE
Service: Interval 180 days Consumables 200 kg
Returnables 0 kg Man hours required 8.00
Configuration Changes: Interval 180 days Man/Hours Required 8.00
Deliverables 1000 kg Returnables 1000 kg

SPECIAL CONSIDERATIONS/See instructions

Figure 4.1.5-4. Mission Data Form, LSS-4 (Continued)

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Boeing-Specific Input Data

MISSION TYPE                                       OPS CODE
   Free Flyer
   ( ) Not Serviced                                   F
   ( ) Remote TMS                                     FT
   ( ) Remote Manned                                  FM
   (X) Serviced at Station (TMS Retrieved)            FST
   ( ) Serviced at Station (Self-propelled)           FS

   Platform Based
   ( ) Not Serviced                                   P
   ( ) Remote TMS                                     PT
   ( ) Remote Manned                                  PM
   ( ) Serviced at Station (TMS Retrieved)            PST
   ( ) Serviced at Station (Self-propelled)           PS

   Other
   ( ) Space Station Based                            SS
   ( ) Sortie                                         SOR

CONSTRUCTION/SERVICING COMPLEXITY
   ( ) Low
   ( ) Medium
   (X) High

Operations Times
   OTV Up/Down                           days
   OTV or TMS on Orbit                   days
   Mission Use                       365 days/year
   IVA Service                        10 man-days/year
   EVA Service                        23 man-days/year
   Experiment Ops                     10 man-days/year
   Service Frequency                   2 times/year

Delta Velocities
   Up
   Down
   Aero Return

Support Equipment
             Length:   2.5   meters     Width:   2.5  meters     Height:  1    meters    (Stowed)
             Length:   26    meters     Width:   12   meters     Height:  3.5  meters    (Deployed)

             Mass:   2000    kg

Manifest Restrictions
   (X) No Restrictions
   ( ) Only with compatible payloads
   ( ) Fly-Alone
   ( ) Must have Docking Module

Length of Beam Fab
Number of Appendages                                   7
Number of Modules Required to Assemble the Payload    82
```

Figure 4.1.5-4. Mission Data Form, LSS-4 (Continued)

The additional groundrules and assumptions used are as follows:

- The Boeing PCM hardware cost model was used to estimate all structural/mechanical items and all support costs i.e. SE&I, system ground test, tool & test equipment, program management etc.

- PCM was used to estimate all integration costs.

- The RCA PRICE hardware cost model was used to estimate the cost of one set of primary mirrors and secondary mirror assembly of the Precision Optical System.

- Design costs for the Construction/Storage Facility, Servicing Hangar and Passive Microwave Radiometer all reflect the design of a few small pieces of hardware duplicated many times in the manufacturing process. This explains the low engineering costs reflected in each of these developmental cost estimates.

- The extendable masts for the Servicing Hangar and Precision Optical System are 100% off-the-shelf.

- The electronics package for the Passive Microwave Radiometer was not priced.

- The electronics instrument package for the Precision Optical System was not priced.

- Learning was assumed (88% of structural items).

- Developmental Quantity = 2 for each TDM structure.

The resulting development and hardware costs for each of the TDM s are shown in Table 4.2-1.

Table 4.2-1. TDM Development Costs

	TDM			
	LSS-1	LSS-2	LSS-3*	LSS-4**
ENGINEERING ($M)	45.1	0.4	19.6	154.6
TOTAL HARDWARE (2 UNITS)	29.5	6.8	100.1	118.8
TOTAL DEVELOPMENT ($M)	74.6	7.2	119.7	273.4

*DOES NOT INCLUDE MICROWAVE SENSORS AND ELECTRONICS
DOES NOT INCLUDE CONSTRUCTION FIXTURE

**DOES NOT INCLUDE FOCAL PLANE ELECTRONICS AND MIRROR CONTROL SYSTEM ELECTRONICS

These costs are based on the development of two sets of hardware, one for development testing and the other for flight tests. In the case of the optical system, only one set of operational mirrors is priced. Simulated mirrors will be used for ground tests.

As a supplement to the cost analysis, transportation costs were estimated to provide a Space Station vs no Space Station cost comparison. A rough-order-of- magnitude comparison was developed for carrying out the four LSS missions using the Shuttle only versus using the Shuttle and an early Space Station. This comparison is shown in Table 4.2-2. Shuttle costs were based on shared launches except for LSS-3 which requires almost all of the payload bay. For the Shuttle-only case, an estimate of the construction equipment that would have to be carried along was made. Also, if the construction time exceeded ten days, revisits were scheduled, and priced on the basis of the construction equipment, the time, and the assumption that these could be shared flights.

The shared-flight assumption may be questionable inasmuch as the orbit lifetime issue would force the LSS missions to the highest altitudes attainable by the shuttle if a Space Station is not available.

The Space Station costs were estimated based on Space Station user charges derived from the Boeing Space Station mission analysis study [10], and on transportation charges appropriate to delivering the LSS missions to a Space Station. The Space Station user charges are high enough to amortize Space Station DDT&E and hence represent a pessimistic view.

Table 4.2-2. Cost Comparison Calculations

TRANSPORT CHARGES—NO SPACE STATION ($M)

MISSION	MASS KG	LENGTH M	CONSTR. EQUIP. MASS	CONSTR. EQUIP. LENGTH	LAUNCH COST	TIME-ON-ORBIT CHARGE	REVISITS COST	TOTAL
LSS-1	2800	2	1800	2	23.8(V) *	7	11.9(V)	42.7
LSS-2	550	1	1800	2	17.9(V)	3	—	20.9
LSS-3	7365	13	4408	4	82 (V)	18	23.8(V)	123.8
LSS-4	5060	5	4400	4	53.6(V)	25	47.6(V)	126.2

TRANSPORT CHARGES—SPACE STATION ($M)

MISSION	MASS KG	LENGTH M	CONSTR. EQUIP. MASS	CONSTR. EQUIP. LENGTH	LAUNCH COST	TIME-ON-ORBIT CHARGE	REVISITS COST	TOTAL
LSS-1	2800	2	270	.3	13.7(V)	–	–	13.7
LSS-2	550	1	–	.15	6.9(V)	–	–	6.9
LSS-3	7365	13		1.5	82 (V)	–	–	82
LSS-4	5060	5	562	0.6	33.4(V)	–	–	33.4

SPACE STATION USER CHARGES ($M)

MISSION	TIME	PORTS	POWER	INTERNAL VOL	DATA	CREW	TOTAL
LSS-1	9 DAYS	1.17	0.43	NONE	0.17	8.64	10.41
LSS-2	4 DAYS	–	–	–	0.08	4.22	4.3
LSS-3	18 DAYS	2.33	0.86	–	0.34	19	22.53
LSS-4	25 DAYS	3.25	1.19	–	0.47	26.4	31.31

*COST DETERMINED BY VOLUME

The cost calculations from Table 4.2-2 are compared in Figure 4.2-1 in bar chart fashion. The no-Space-Station bars include three increments, for launch cost, time-on-orbit charge, and revisits cost. The Space Station bars include the transportation and Space

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Station charge increments. There is clearly an economic benefit in conducting TDMs on a Space Station, particularly for LSS-4 where the transportation and on-orbit costs are approximately half of the comparable costs without a Space Station.

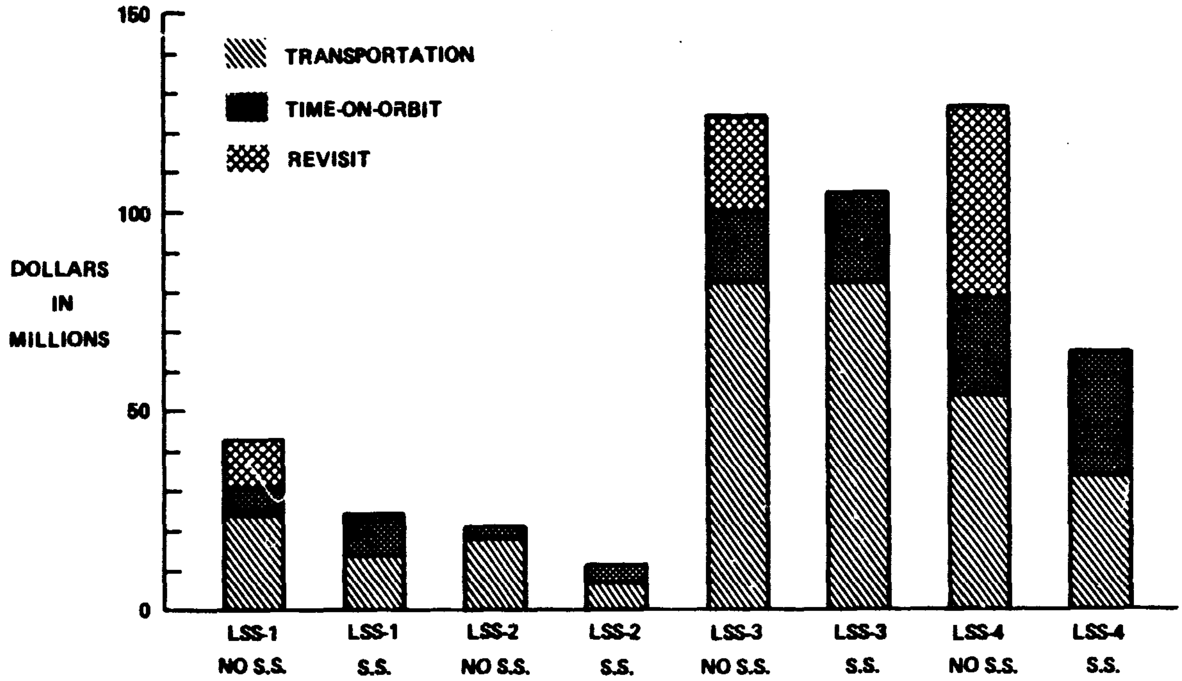

Figure 4.2-1. No Space Station Versus Space Station Cost Comparison

- SRT & Advanced Technology Requirements
- Technology Development Experiment Hardware
- Flight Support Equipment (FSE)
- Ground Support Equipment (GSE)

o Cost estimates exclude:

- STS Transportation
- Upper Stages

o Contractor develops all other ground rules required to develop cost estimates for their specific study and state these ground rules in the report.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The systematic study of the construction of large space structures in space leads to the conclusion that a Space Station is required to provide a manned stable platform for construction. The long construction and checkout timelines preclude the assembly of large space structures during a single Shuttle flight, and the rapid orbit decay of unattended structures prevent or, at least, complicate revisits by the Shuttle. The Space Station thus reduces the number of Shuttle flights and, therefore, transportation costs. With systematic construction and step-by-step checkout, the spacecraft can be made less complex and the risks associated with LSS construction are significantly reduced.

It is recommended that several of the areas of the current study be investigated in more depth to provide more detailed TDM designs. Also, for the large space structures technology development missions to be economical and technically compatable with Space Station operations, further analyses must be conducted to determine 1) the relative costs involved with various construction methods 2) the influence of the structure on TDM system operational performance and 3) the interaction of the large space structure with the Space Station. In particular, the following topics should be pursued:

Expansion of Current Study Areas - Several tasks in the current study require additional effort to provide more detail. TDM design details are required in the area of structural joints, deployment mechanisms, subsystem installation methods and structural alignment and adjustment mechanisms. More specific programmatics information can be developed in the areas of costs and schedules in light of funding constraints. A study should also be conducted to demonstrate how the Space Station accommodation requirements determined in the present study can be met on two specific Space Station architectural concepts.

Construction Options - It is not clear that there is a "best" way to construct a spacecraft which requires a large space structure. A complex deployable spacecraft will have high design and manufacturing cost but may require a short time period on orbit to become operational while an assemblable spacecraft may cost less to manufacture but will require a long time on orbit to assemble. A compromise design consisting of the assembly of deployable modules is also a possible option. The cost of these scenarios should be considered along with the resulting spacecraft performance to determine the most economical use of resources.

TDM Operational Performance - Two of the TDMs are designed to become operational free-flyer spacecraft following their use as deployment/assembly demonstration experiments. The resulting structure must be sized to provide sufficient strength for any operational loading condition and to provide the stiffness necessary to reduce static and dynamic structural deformations to acceptable levels and to prevent undesirable structure/control interaction. Therefore analytical models of each TDM structure should be developed to assess the preliminary structural sizing in terms of strength, stiffness and possibly thermal deformations.

TDM/Space Station Interaction - While the large space structures are attached to the Space Station they must not jeopardize the operational capabilities of the Space Station. The interaction of the TDMs with the Space Station must be assessed, particularly in the area of control stability. The dynamic models of the TDMs can be used to estimate the influence of large space structures on the dynamic characteristics of a postulated Space Station design.

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